(2)

AD-A210 799

WRDC-TR-89-2028

DEVELOPMENT OF A HIGH TEMPERATURE FZG-RYDER GEAR LUBRICANT LOAD CAPACITY MACHINE

Dr.-Ing. K. Michaelis
Prof. Dr.-Ing. H. Winter
Gear Research Laboratory FZG
Technical University of Munich
Arcisstraße 21
8000 Munich, Germany

May 1989

Final Report for Period September 1986 to December 1988

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

AERO PROPULSION AND POWER LABORATORY
WRIGHT RESEARCH AND DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6563

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

Howard F. Jones

HOWARD F. JONES, Chief
Lubrication Branch
Fuels and Lubrication Division
Aero Propulsion and Power Laboratory

FOR THE COMMANDER

Benito P. Botteri

BENITO P. BOTTERI, Chief
Fuels and Lubrication Division
Aero Propulsion and Power Laboratory

If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization, please notify WRDC/POSL, Wright-Patterson AFB OH 45433-6563 to help us maintain a current mailing list.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS N/A
2a. SECURITY CLASSIFICATION AUTHORITY N/A	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release, distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) F515/2/Mi 1583	5. MONITORING ORGANIZATION REPORT NUMBER(S) WRDC-TR-89-2028
6a. NAME OF PERFORMING ORGANIZATION Technical University of Munich 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Aero Propulsion and Power Laboratory, Wright Research and Development Center
6c. ADDRESS (City, State, and ZIP Code) Arcisstraße 21 8000 Munich, Germany	7b. ADDRESS (City, State, and ZIP Code) Wright-Patterson AFB OH 45433-6563
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Aero Propulsion and Power Lab 8b. OFFICE SYMBOL (If applicable) WRDC/POSL	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F49620-86-C-0081
8c. ADDRESS (City, State, and ZIP Code) Wright-Patterson AFB OH 45433-6523	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 62203F PROJECT NO. 3048 TASK NO. 06 WORK UNIT ACCESSION NO. 46

11. TITLE (Include Security Classification)
Development of a High Temperature FZG-Ryder Gear Lubricant Load Capacity Machine

12. PERSONAL AUTHOR(S)
Dr.-Ing. K. Michaelis, Prof.Dr.-Ing. H. Winter

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 86/9/1 TO 88/12/31	89, May, 16	81

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Load Capacity, Lubricant, Test Methods, Correlation
11	08		
14	02		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A modified FZG-Ryder gear machine was developed to run scuffing tests at high speed ($n_1 = 9700\ min^{-1}$) and oil temperatures from 74°C to 200°C. Test oil volume is approximately 3 liters. Good correlation was found between FZG-Ryder and standard Ryder test results when rating ester base lubricants and using ester base reference oils such as Hercolube "A". Poor correlation was found when using mineral based reference oil "C". Tests on three oils at 200°C showed considerable lower load capacity as compared to ratings at 74°C. However, relative ranking of the lubricant was unchanged.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Howard F. Jones	22b. TELEPHONE (Include Area Code) (513) 255-5568 22c. OFFICE SYMBOL WRDC/POSL

DD Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

PREFACE

This technical program was performed under research Contract F49620-86-C-0081 and sponsored jointly by the US Air Force European Office of Aerospace Research and Development (EOARD), Air Force Office of Scientific Research, Air Force Systems Command and the Aero Propulsion and Power Laboratory, Air Force Wright Research and Development Center, Air Force Systems Command. Program managers were Major Thomas Speer, EOARD and Mr. Howard Jones, WRDC/POSL. Work was accomplished during the period of September 1986 to December 1988.

TABLE OF CONTENTS

1. Introduction

The objectives of this research were as follows:

a. Development, design and manufacture of a high speed, high temperature back-to-back gear test rig based on the FZG-Ryder Rig.

b. Define correlation between standard U.S. Ryder and FZG-Ryder results by the evaluation of the scoring load capacity of 5 different lubricants acc. to Standard FZG-Ryder Method.

c. Comparative testing of different lubricants acc. to the Standard FZG-Ryder Method in the Standard and the High Temperature FZG-Ryder Rig.

d. Evaluation of the scoring load capacity of different lubricants under high speed and high temperature conditions on the FZG-Ryder rig.

e. Preparation of Operating and Repair Manuals.

f. Installation of the High Temperature FZG-Ryder Rig at Wright Patterson Air Force Base, Ohio.

2. Test Equipment

2.1 Test Rig

2.1.1 Standard FZG-Ryder Rig

The Standard FZG-Ryder Gear Test Rig operates on the so called "four square" principle. As shown in Fig. 1 the test gears and the slave gears are connected by two parallel shafts. The load clutch divides one shaft into two halves that can be twisted against each other by means of a spindle device. The applied torque can be determined from a dial gauge in the measuring clutch that measures the deflection of a calibrated torsional shaft. After fastening the load clutch a static torque is

introduced in the mechanical power circuit of the rig. The driving motor has only to compensate for the frictional losses in gears and bearings. The system is driven by a two-speed AC-motor and for adjusting the high speed a speed up gear is coupled between motor and slave gears.

The test rig is a modified FZG machine as it is used for the Standard FZG Oil Test A/8.3/90 acc. DIN 51 354 [1] respectively CEC L-07-A-85 [2]. It was developed under the sponsorship of the German Ministry of Defence as an alternative test method to the Original Ryder Gear Test acc. FTM 6508 [3] respectively ASTM-D 1947 [4]. A comparison of the main data of the original Ryder test and the FZG-Ryder test is given in Table 1 [5]. It can easily be seen that the main data of the two methods do not differ very much. The biggest difference is in the load application. While in the original Ryder test the load is applied by an axial displacement of the helical slave gears by means of hydraulic pressure during the rig is running in the FZG-Ryder test the load is applied while the rig is out of operation. In the original Ryder machine the journal bearings of the test gears are lubricated separately while in the FZG-Ryder rig the anti-friction bearings have to be lubricated by the jet oil sprayed on the gears. Therefore the oil flow rate was increased for the FZG-Ryder Method.

Two separate oil supply systems are used for the lubrication of the test gear box and the slave and speed-up gear boxes. The test oil supply system uses 6-8 l test lubricant while the slave oil supply system uses 30 l of a standard low viscosity lubricant. A heating and cooling system in the oil tanks maintains an oil temperature of $\vartheta_{oil} = 74 \pm 2°C$. The principle of the oil supply system is shown in Fig. 2. A gear pump sucks the oil from the reservoir tank and presses it through a water operated heat exchanger and filter into the gear mesh. The oil quantity can be adjusted by opening or closing the bypass-valve. An electric heater of low heat transferred per unit surface to avoid overheating of the lubricant (= 0.7 W/cm²) is placed in the oil tank. Heating or cooling is controlled by a thermometer with electrical contacts to switch the heater on or off respectively to open or close a solenoid valve for the

water flow to the heat exchanger. A pressure gauge with minimum and maximum electric contacts controls the oil flow. The test rig is switched off when either minimum pressure (e.g. oil hose disconnected) or the maximum pressure (e.g. blocked nozzle) is exceeded.

For the evaluation of the scored area on the flanks a microscope can be placed over the test gear box (Fig. 3).

2.1.2 High Temperature FZG-Ryder Rig

For the required evaluation of the scoring load capacity of aircraft lubricants at high speeds and high temperatures the standard FZG-Ryder rig was modified to allow for oil inlet temperatures of at least 200°C. Additionally, the necessary test oil quantity should be reduced to approx. 3 liters.

The following main modifications were made:

1. The test gear box was thermally insulated from the bed plate by means of an air gap.
2. A double-walled cover was placed over the test gear box to reduce radiation and convection and to provide a certain contact protection of very hot parts.
3. Additional heating elements were installed in the test gear box.
4. A completely new test oil supply system was developed, designed and built to meet the high temperature and the low volume requirements.

Additionally, all parts including the bearings were annealed to temperatures up to 250°C to avoid temperature distortion.

Fig. 4 shows the H.T. oil supply system. The test gear box bottom is used as oil tank. Four heating elements 500 W each are placed in the front cover and the rear wall of the test gear box. Another 8x90 W plus 17x90 W heating elements are placed in an external heat exchanger. The oil inlet temperature is controlled by two thermometers at the oil inlet and the oil outlet with four electric contacts switching the heaters on and off. The inlet oil quantity is controlled with

a flow meter changing the speed of the variable speed drive of the oil pump. A mean value for the oil quantity to maintain a minimum oil pump speed is set with the by-pass value. The system can be drained by means of a drain valve and at the filter as the lowest level point of the system. The total amount of oil in the system is approx. 3 liters.

A cooling system was not installed because of

- o problems with a water cooling system at high temperature (200°C) operation and
- o problems with an air cooling system with size and thus oil quantity.

An assembly drawing of the mechanical part of the High Temperature FZG-Ryder Rig is shown in Appendix A.

2.2 Test Gears

Due to the almost same center distance of the Standard Ryder Rig and the FZG-Ryder Rig very similar gears could be designed for the FZG-Ryder Method. A comparison of Original Ryder and FZG-Ryder test gears is shown in Table 2.

For simple manufacture in Germany a standardized metric module was chosen and a standard German steel which is very similar to the U.S. AMS 6260 steel which is used for the original Ryder gears. A comparison of the material's analysis is given in Table 3. A profile modification (tip relief) was applied to the wider gear (= gear) of C_a = 15 µm to meet the absolute values of the original Ryder results.

Fig. 5 shows the load and speed distribution for the FZG-Ryder gears type R along the path of contact. Fig. 6 shows the manufacturing drawings of the narrow (= pinion) and the wide (= gear) gear.

The test gears for this project were taken from a batch of 60 gear pairs manufactured by Zahnradfabrik Friedrichshafen (ZF). A sample of 10 test gear pairs was measured for quality control. One test gear pair was cut into pieces for metallurgical investigation.

2.2.1 Geometrical Measurements

2.2.1.1 Measuring Devices and Measured Values

Roughness values were measured on a "Perthometer S5" using a digital evaluation unit "µ-tip" (Fa. Manner). The measured values and a profile diagram were printed with a HP plotter.

Profile errors and lead errors were measured on a "Klingelnberg PFSU 1200".

Additionally the tooth to tooth pitch error was evaluated on a "Höfler UP 400".

2.2.1.2 Roughness Measurement

Three teeth equally distributed around the circumference of the gear were measured on both flanks. The flanks were measured in involute direction using a trace length of 1.25 mm and a cut-off of 0.25 mm.

The following values were measured:
- center line average height (CLA)
- total height (peak to valley PTV)
- roughness height over 10 points (mean value PTV)

An example is shown in Fig. 7.

2.2.1.3 Measuring of Profile and Lead

From a profile and a lead diagram of three teeth of every gear on both flanks the following values were graphically evaluated:

- total profile error F_f
- total alignment error F_β
- tip relief of gear C_{a2}

The total length of the path of contact (approx. 14 mm from tooth tip) was used for the evaluation of the total profile error of the pinion (narrow gear) while for the evaluation at the gear (wide gear) the region of the tip relief was not

taken into account. The profile error of the gear was taken from the path of contact between approx. 3 mm and 14 mm from the tooth tip.

The alignment error was evaluated from the whole tooth width of the pinion and only from the active part of the gear, i.e. approx. 8 mm in the center of the gear.

Fig. 8 shows as an example a diagram of the pinion, Fig. 9 of the gear.

2.2.1.4 Measuring of Pitch Error

From the diagrams the tooth-to-tooth pitch error f_u was evaluated. Examples are shown in Fig. 8 and 9.

2.2.2 Results of the Measures

The results for the 10 gear pairs can be taken from table 4. The total alignment error F_β is not included in the table because all measured values were below 2.5 µm, what is the permissible value for best quality DIN 1 (AGMA ≈ 17-DIN).

The DIN quality was correlated to the worst value out of total profile error or tooth-to-tooth pitch error. The values of roughness height over 10 points and tip relief included in the table are mean values out of the three measures on one flank side.

2.2.3 Conclusions of the Geometrical Quality

The gear quality of DIN 5 acc. to the drawings is in 18 cases out of 20 within the demanded limits. In two cases DIN quality 6 is reached due to the pitch error.

The roughness height over 10 points is in all cases far below the tolerated value acc. to the drawings of R_z = 3 µm.

The tip relief is in many cases somewhat smaller (9 - 10 µm) than the tolerances given on the drawings (12 - 18 µm).

In spite of minor deviations of the gear quality compared to the stated quality in the drawings, the gears are to be used for correlation tests.

2.2.4 Metallurgical Investigation

One pinion and gear was checked for

- burnishing from grinding process
- material structure and retained austenite
- case and core hardness and case depth

2.2.4.1 Burnishing

A microscopical investigation on the flanks of pinion and gear showed no evidence of burnishing from the grinding process. The machining of the flanks is in accordance with the demands on the drawings.

2.2.4.2 Material Structure and Retained Austenite

A ground and polished section of one pinion and gear tooth was prepared. Fig. 10 shows the material structure of the pinion, Fig. 11 of the gear. In both cases tempered martensite with approx. 9% retained austenite is present.

The retained austenite was evaluated graphically after the sections were colour-etched acc. to Klemm.

The material structure shows no irregularities. The content of retained austenite is low and in accordance with the demands on the drawings.

2.2.4.3 Hardness Measurements

Fig. 12 shows the hardness as a function of the depth for the pinion, Fig. 13 for the gear. The surface hardness of 686 HV 10 for the pinion and 693 HV 10 for the gear is in accordance with the drawings. The case depth of the pinion of 0.8 mm and of the gear of 0.67 mm is somewhat higher as required. The

ultimate strength in the core is with approx. 1400 N/mm² for the pinion and approx. 1300 N/mm² for the gear also higher than the required value of 1000 - 1200 N/mm².

As scuffing failure is concentrated at the very surface of the tooth flanks these differences in case depth and core hardness have no influence. Also surface hardness is of minor influence as long as the material structure near the surface is adequate. A steep decrease in scuffing load capacity can be observed for retained austenite contents of more than approx. 20%.

2.2.4.4 Conclusions of the Metallurgical Quality

The gears do not show any grinding defects like burnishing or grinding cracks.

The structure in the case is normal with tempered martensite and a low content of 9% retained austenite.

The surface hardness is of the magnitude as required. The case depth and the core hardness are somewhat higher than required which is assumed to have no influence on the scuffing behavior.

2.2.5 Conclusions

The test gears are of good and uniform quality. Minor deviations from the demands on the drawings will not affect the expected scuffing results in a way that the gears have to be rejected. The somewhat to small values of tip relief can lead to somewhat lower scuffing load capacity as compared to earlier results. This takes only influence on the absolute rating but not on a relative rating comparing scuffing load of a candidate oil with that of a reference oil.

The gears can be used for the test program.

2.3 Test Lubricants

The lubricants used in this project are listed in Table 5 together with their typical values in the original Ryder test. Lubricants numbers. 1, 3, 4 and 5 were provided by Mr. H. Jones, WPAFB, USAF, lubricants 2 and 6 by Mr. A. Kling, WIM, German Army.

3. Test Method

The standard FZG-Ryder Method was established close to the original Ryder Method [3, 4]. The High Temperature FZG-Ryder Method was chosen accordingly except the higher oil inlet temperature.

In the following the Standard Method is described. Differences to the H.T. Method are marked when necessary. For details of test rig operation, gauge setting, and test gear mounting and dismounting see also "Operating and Repair Manual".

3.1 Preparation of the Test Equipment

All test gears should be numbered on one of their gear faces. Looking on the numbered face the left flank is defined as side A the right flank as side B. Tooth no. 1 (e.g. the tooth nearest to the key) on the pinion is marked on the outside diameter. The narrow gear (called "pinion") is mounted on the right shaft (looking from the test head in direction of the motor; the shaft carrying the load clutch) the wide gear (called "gear") on the left shaft (carrying the measuring clutch) with the numbered face pointing to the front cover. The left hand flank or side A will be operating. During mounting the gears it has to be observed to position the two grooves of the load clutch relatively to the holder of the dial gauge on the measuring clutch so that with the spindle device mounted on the load clutch the dial gauge is positioned approx. horizontal.

Then the microscope is positioned over tooth no. 1 of the pinion and the position is marked on the load clutch and the support bearing.

The pinion tooth width is centered within the gear tooth width. The front cover is closed, and 3 liters of test lubricant are filled into the gear box. Then the top cover is closed and the oil supply system prepared for operation. For high temperature operation the insulation cover has to be placed over the test gear box.

Depending on the desired test oil temperature the electric contacts of the thermometers are adjusted. The following figures can be used as a guidance.

For ϑ_{oil} = 74°C (Standard Test Method):

Test Gear Oil Temperature:

Outlet:	green:	20°C (no heating of test gear box)
	red:	110°C (max. oil temperature in the system)
Inlet:	green:	69°C (switch off of 8x90 W)
	red:	72°C (switch off of 17x90 X)

Slave Gear Oil Temperature:

Oil tank:	green:	30°C (start of oil pump)
	red:	110°C (max. oil temperature in the system)
Inlet:	green:	70°C (switch off of 1400 W)
	red:	75°C (switch off of 700 W)

For ϑ_{oil} = 200°C (High Temperature Test):

Test Gear Oil Temperature:

Outlet:	green	190°C (switch off of 4x500 W)
	red:	210°C (max. oil temperature in the system)
Inlet:	green:	195°C (switch off of 8x90 W)
	red:	200°C (switch off of 17x90 W)

Slave Gear Oil Temperature:

Oil tank:	green:	30°C (start of oil pump)
	red:	110°C (max. oil temperature in the system)
Inlet:	green:	90°C (switch off of 1400 W)
	red:	95°C (switch off of 700 W)

The two lube systems and their heaters are switched on with the gears unloaded and the motor switched off. After the desired temperatures are reached (after approx. 1 hour) the oil level in the test gear box is controlled. The oil level must be within 35 (min.) and 40 mm (max.) over the test gear box ground. For higher oil levels the gears dip into the lubricant and high churning losses occur, for lower oil levels the gear box is overheated by the 4 x 500 W heaters. To take account of the thermal expansion of the oil the oil level has to be adjusted at operating temperature. For too low oil level pour some more lubricant into the rig, for too high level drain some lubricant at the drain valve using protective gloves against high temperatures.

The oil flow in the slave gear box and the speed up gear box is adjusted to approx. 3 - 4 l/min by closing the by-pass valve. The oil amount has to be determined once for the lubricant used at operating temperature by means of volume and time measurement. For the same lubricant at the same temperatures the oil pressure reading is proportional to the oil flow rate. For further testing the once calibrated oil pressure level has simply to be readjusted. An optimum setting of the by-pass valve is reached when the gear oil pump operates at medium speed (Flow Rate Setting approx. 5).

Too low flow rate in the slave and speed up gear box can cause cooling problems and at the worst lubricant starvation conditions with heavy scoring in the slave and speed up gear. Too high flow rate can cause problems in oil draining from the two gear boxes back to the oil tank and thus dipping of the gears into an oil sump thus foaming of the oil in the gear boxes and an overflow of the lubricant.

Test lubricant supply is adjusted to the flow rate of 1 l/min with the by-pass valve opened that far that the flow rate setting operates at a value of approx. 5 on the scale. In this case an optimum range of regulation of the flow rate is achieved and the oil pump operates at medium speed.

The revolution counter and switch is set to 970 what is equal to 97 000 revolutions (preset factor 100 x) corresponding to 10 minutes running time at nominal speed of $n_1 = 9700\ min^{-1}$. Due to slight differences in the speed of an AC motor as a function of load slight deviations from 10 min running time can occur.

3.2 Running of the Test at Stepwise Increased Load

For load application the left half of the load clutch is fixed to the support bearing with the locking pin in position that the grooves on the two halves of the load clutch are approximately vertical and the holder of the dial gauge on the measuring clutch is approximately horizontal. Then install the dial gauge in its holder. Before the application of the first load stage the test rig should be overloaded statically for one minute at load stage 10 to avoid gradual load decrease during running at low load stages due to backlash and play in the system especially in the keys.

Then the zero point is adjusted on the dial gauge. The next load stage is applied acc. to the values given in Table 6. The given gauge settings only apply for the torsional shaft No. S18/23 with diameter 18 mm as it is delivered with the rig. In case that a new torsional shaft is mounted this shaft has to be calibrated separately. The low loads can be applied by hand with the delivered lever the high loads by using the delivered spindle device. The load application must be in a direction that the pinion drives the wheel in the test gear box, i.e. a weight loading on the lever respectively a "closing of the scissors" of the spindle device. When the adequate load is applied and controlled with the dial gauge the units of the load clutch are tightened, the spindle device, the dial gauge and the locking pin are removed. Make sure by turning the shafts by hand that all blockings have been removed and close the protecting cover before operation.

Now the motor can be switched on. After the completion of the preset number of revolutions the rig shuts down automatically. For further safety regulations see Operating and Repair Manual.

After every load stage the load is removed from the gears by untightening the bolts of the load clutch. For the evaluation of the failures on the gears and the application of the next load stage a maximum time of 10 minutes must not be exceeded.

3.3 Evaluation of the Test Result

After every load stage the active flanks of the pinion are inspected for scuffing failures. The inspection is performed by use of the microscope with the evaluating grid in the ocular. The inspection hole in the top cover is opened and the microscope is positioned above. During the inspection the oil supply is still in operation. Make sure that the exhaust fan is also working. Then position tooth no. 1 into the microscope by matching the marks on the load clutch and the supporting bearing. Evaluate the area scuffed using the grid in the microscope and mark it in a diagram as shown in Fig. 14. Then turn the pinion shaft counter clockwise (looking from the test head in direction of the motor) to the next tooth and repeat the evaluation. After completion of the failure reading either stop the test in case that the damaged area exceeds approx. 30% of the total active area of the pinion; otherwise apply the next load stage as described in clause 3.2.

The exact scuffed area in % of the active flank area can be estimated by summing up the scuffed parts of the grid of every tooth and dividing it by the total amount of active "grid" areas (= 30 x 20 = 600).

The total relative scuffed flank area is plotted against the load stage in a half-logarithmic chart as shown in Fig. 15. The scuffing load is defined as interpolated normal tooth load where 22.5% of the active flank area are scuffed. The interpolation can be done graphically as shown in Fig. 15 or according to the algorithm using the following terms:

S_1 - load stage (integer) prior to 22.5% scuffed area

S_2 - load stage (integer) over 22.5% scuffed area

S_S - load stage (decimals) where exactly 22,5% are scuffed

A_1 % percent scuffed area in load stage S_1

A_2 % percent scuffed area in load stage S_2

F_S lb/in scuffing load per face width (for 22.5% scuffed area)

$$S_S = \frac{\log 22.5 - \log A_1}{\log A_2 - \log A_1} + S_1$$

$$F_S = 375 \cdot S_S$$

with $S = 375$ lb/in per load stage

One lubricant is at least tested on the two flanks of one gear pair. The results of every tooth side (A and B) and the mean value are reported.

A brief summary of the Standard FZG-Ryder Method can be taken from Fig. 16.

3.4 Relative Rating of Test Results

Every new test rig and every new test gear batch have to be rated against a reference lubricant. For aircraft lubricant application it is recommended to use an ester-based reference lubricant of approximately same viscosity as the lubricants to be tested, e.g. Hercolube A. With a high viscosity, miner based reference lubricant like Reference Oil C major deviations in the original Ryder and the FZG-Ryder results were found (see Chapter 4).

The result of the load carrying ability of a candidate lubricant can then also be expressed in % of the reference lubricant:

$$F_{S\%} \text{ (Candidate)} = \frac{F_S \text{ (Candidate)}}{F_S \text{ (Reference Oil)}} 100\%$$

To check the rig it is recommended to run duplicate tests on the reference oil after every e.g. 20 candidate lube tests.

4. Results of the FZG-Ryder Tests

The different tests were performed on the test rig built under this contract for the USAF. For the first series of Standard FZG-Ryder tests a standard oil supply system (see clause 2.1.1) was used. Then the rig was modified for high temperature application and the new high temperature oil supply system was installed. In the second series of standard FZG-Ryder test the high temperature oil supply system was used at nominal 74°C inlet temperature and in the third series of high temperature FZG-Ryder tests the h.t. oil supply system was used at 200°C inlet temperature.

All tests were performed using the actual driving motor of the USAF-rig at German power supply conditions, i.e. 380 V and 50 Hertz. This was possible because the motor is of the multi-voltage and multi-cycles type. To arrive at the same pinion speed a different gear set in the speed up gear was used for testing in Germany. The gear ratio for 50 Hz (used for the tests) was $z_2/z_1 = 3.3$. The delivered gear ratio for 60 Hz is $z_2/z_1 = 2.7$ what compensates for the higher nominal motor speed at 60 cycles.

Tables containing all test results as well as diagrams of the failure development are given in Appendix B. The results are summarized in Table 7.

The results were statistically evaluated acc. [7, 8]. The values in Table 7 are determined as follows:

$$\text{Mean M:} \quad m = \frac{\sum_{i=1}^{n} F_{Si}}{n}$$

Standard Deviation S.D.:

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (F_{Si} - m)^2}$$

From these results the repeatability r (one lab, one machine, one operator etc.) can be calculated:

$$r = 2.8 \cdot s$$

All data were checked acc. to the Cochran-Test, there were no outliers.

4.1 Standard FZG-Ryder Tests Using Standard Oil Supply System

The tests were performed for lubricants numbers 1 through 5 (Table 5).

Due to problems with the oil flow rate measurement tests nos. 1 - 8 with Hercolube A (oil 2) were run at an oil flow rate of approx. 4 l/min and test nos. 9 - 12 with TEL 7038 (oil 3) at an oil flow rate of approx. 2.5 l/min instead of 1 l/min. The results were considerably higher than expected. After reducing the oil flow rate to 1 l/min tests nos. 13 - 40 showed consistent results (see Table 7). A comparison of the original Ryder and the FZG-Ryder Results can be taken from Fig. 17. Following tests nos. 41 - 48 with Reference Oil C (oil 1) showed divergent results. While Refoil C was supposed to show the highest scuffing load acc. to the original Ryder results the FZG-Ryder tests gave the lowest results of the five tested oils.

An explanation could not be found. Refoil C is a mineral based lubricant of completely different viscosity grade as compared to the other ester type oils.

Exept of the unexpected behavior of oil 2 the other lubricants showed absolutely higher scuffing ratings in FZG-Ryder Test as compared to the original Ryder test. This could be adjusted in further investigations by either reducing the oil flow rate (see clause 4.2) or manufacture of test gears without tip relief.

4.2 Standard FZG-Ryder Tests Using High Temperature Oil Supply System

After modification of the test rig and the manufacture of the h.t. oil supply system with an oil quantity of 3 l comparative tests at standard inlet oil temperature of ϑ_{oil} = 74°C were run with oils nos. 1 and 2. Additionally, the oil flow rate was changed to 0.5 l/min. The test results of tests nos. 49 - 56 are summarized in Table 7, details can be taken from Appendix B. Due to lack of test gears only two test runs were performed for one parameter combination. In the higher loads starting approx. with load stage 7 the standard oil temperature of ϑ_{oil} = 74°C could no longer be held constant. The temperature rises to approx. 85°C in load stage 10. The problem could not be solved because the addition of a water cooler would cause extreme problems at ϑ_{oil} = 200°C and an air cooler would increase the necessary oil volume considerably.

At 1 l/min oil flow rate the scuffing load capacity of Hercolube A (oil 1) lay in the same scattering range as the results obtained with the standard oil supply system. The results at 1 l/min oil flow rate of the Refoil C were now considerably higher. The relative rating was now 112% of Hercolube A compared to 131% in the original Ryder tests. This is still somewhat too low but compared to former results (clause 4.1) at least in the right order of magnitude. An explanation could not be found.

The results at different oil flow rate of different tests in clause 4.1 and 4.2 at standard inlet temperature ϑ_{oil} = 74°C are compared in Fig. 18. Although there are only a few test results available the following tendency seems to be clear:

For the low viscosity ester based lubricants (oil 1 and 3) the scuffing load increases slightly with increasing oil flow rate. There is hardly a difference between oil flow rate of 0.5 and 1.0 l/min for these lubricants. In contrary to that the decrease of the oil flow rate from 1 l/min to 0.5 l/min causes a drastic drop in the scuffing load capacity for the

Refoil C (oil 2). This might be due to the high viscosity level of this lubricant and thus completely different flow characteristic and heat transfer ability.

Further tests to clarify the situation were not possible because of a lack of test gears.

4.3 High Temperature FZG-Ryder Tests

High temperature test with an oil inlet temperature of ϑ_{oil} = 200°C were run with oils nos. 2, 5 and 6. The results can be taken from Table 7 and Appendix B. They are summarized in Fig. 19.

The absolute scuffing load capacity of the non EP reference oil Hercolube A (oil 1) as well as for the EP containing lubricants TEL-7040 (oil 5) and Shell Asto 555 (oil 6) dropped to quite an extent as compared to the results at ϑ_{oil} = 74°C (see Fig. 19, a and b). The ranking of the different lubricants at low temperature (Fig. 19a) and high temperature (Fig. 19c) did not change but the relative load carry capacity is somewhat different at high temperatures. A general tendency cannot be derived from the few tests performed. Nevertheless it is obvious from Fig. 19 (a and c) that the relative load carrying capacity at low temperatures cannot simply be correlated to high temperature performance.

5. Remaining Problems

5.1 The oil inlet temperature of ϑ_{oil} = 74°C cannot be kept constant in higher load stages due to the small amount of test lubricant.

Addition of a water cooler would result in somewhat higher test oil volume and would cause considerable problems at high temperature operation (vapour!). Addition of an air cooler would result in considerably higher test oil volume.

5.2 The measurement of the oil flow rate is only excact for lubricants of operating viscosities less than 15 mm²/s. This is no problem with all aircraft lubricants at 74°C or 200°C but it is not exact for Refoil C at 74°C. For Refoil C and ϑ_{oil} = 74°C a reading of 1.5 l/min corresponds to an actual oil flow rate of 1 l/min as required. If necessary the oil flow meter must be calibrated for higher viscosity grades.

5.3 In high temperature tests at ϑ_{oil} = 200°C lubricant filters of nominal grade of filtration between 5 µm and 25 µm had to be replaced continously due to blocking (decrease in oil flow rate!). There were no problems at 74°C with these filter elements.
For further testing filter elements with a nominal grade of filtration of 50 µm were used.

5.4 There is only one test gear pair left.

6. Summary

6.1 A modified FZG-Ryder Gear Machine was developed, designed and manufactured with the capability to run FZG-Ryder Scuffing Tests at high speed (n_1 = 9700 min^{-1}) and standard (ϑ_{oil} = 74°C) or high (ϑ_{oil} = 200°C) oil inlet temperatures. The oil volume required is approx. 3 l.

6.2 Comparative tests at Standard FZG-Ryder Conditions with aircraft ester lubricants gave good correlation with original Ryder results of the same lubricants. There was only very poor correlation using the high viscosity mineral based Reference Oil C. An explanation could not be found. It is recommended to use an ester type lubricant like Hercolube A as a reference lube.

6.3 Tests with three lubricants at high temperature conditions (ϑ_{oil} = 200°C) showed considerably lower scuffing load capacity as compared to ϑ_{oil} = 74°C. The ranking of the lubes does not change but the relative load capacity is different at the different temperatures. That means that results at low oil temperatures cannot easily be correlated with high temperature conditions.

References

[1] DIN 51 354: Prüfung von Schmierstoffen in der FZG-Zahnrad-Verspannungs-Prüfmaschine.

[2] CEC L-07-A-85: Load Carrying Capacity Test For Transmission Lubricants.

[3] FTM STD No. 791: Load Carrying Ability of Lubricating Oils (Ryder-Gear-Machine).

[4] ASTM D 1947: Standard Test Method for Load-Carrying Capacity of Petroleum Oil and Synthetic Fluid Gear Lubricants (reapproved 1982).

[5] Winter, H.; Michaelis, K.: Scoring Tests of Aircraft Transmission Lubricants at High Speeds and High Temperatures. Journal of Synthetic Lubrication 3 (1986), S. 121 - 135.

[6] Winter, H.; Michaelis, K.; Funck, G.: Der FZG-Ryder Freßtest für Flugturbinenschmierstoffe. Tribologie + Schmierungstechnik 35 (1988) H. 1, S. 30 - 37.

[7] DIN/ISO 5725: Bestimmung der Wiederholbarkeit und Vergleichbarkeit durch Ringversuche (Nov. 1981).

[8] DIN 51 848: Präzision von Prüfverfahren.

Table 1: Comparison of Machines and Operating Conditions of Original Ryder and FZG-Ryder Test.

	Original Ryder	FZG-Ryder	Units
load application	axial displacement	torque	
load measurement	recalculated from hydraulic pressure	distortion of calibrated shaft	
center distance	88.9	91.5	mm
pinion speed	10 000	9706	rpm
pitch line velocity	46.5	46.5	m/s
spray lubrication:			
oil flow rate	0.27	1.0	l/min
oil temperature	74	74	°C

Table 2: Comparison of Original Ryder and FZG-Ryder Gears.

		Original Ryder	FZG-Ryder	Units
center distance	a	88.9	91.5	mm
number of teeth	z_1/z_2	28/28	30/30	-
module	m	3.175	3.0	mm
working pressure angle	α_{wt}	22.5	22.5	°
tooth width	b_1/b_2	6.35/26	6.35/26	mm/mm
tip relief	C_{a2}	0	15	µm
relative sliding speed	v_{gmax}/v	0.28	0.28	
material:				
case carburized		AMS 6260	14NiCr14	-
surface hardness	HRC	60-62	60-62	-
surface roughness	CLA	0.3-0.5	0.3-0.5	µm

Table 3: Comparison of Gear Materials of Original Ryder and FZG-Ryder Gears

mean content of	AMS 6260	14 NiCr 14
C	0.11 %	0,15 %
Si	0.27 %	0.25 %
Mn	0.55 %	0.40 %
P_{max}	0.025 %	0.035 %
S_{max}	0.025 %	0.035 %
Cr	1.2 %	0.80 %
Mo	0.12 %	-
Ni	3.25 %	3.5 %

Table 4: Survey on measured values (pinion: without tip relief, gear: with tip relief).

Gear no.	F_f max in µm	f_u max in µm	DIN qual.	reason f. qual. F_f	reason f. qual. f_u	mean value tip relief C_{a2}	mean value PTV in µm R_z
25046 li	2,5	5	4		x	11,5	0,94
25046 re	3,5	5,5	5		x	14	0,77
24986 li	5	2,5	5	x			0,83
24986 re	4	1,5	4	x			0,89
25078 li	2,5	3,5	3		x	12	0,89
25078 re	3	5,5	5		x	12,5	1,63
25018 li	4,5	1,5	5	x			1,0
25018 re	4	2	4	x			0,93
25053 li	3	6,5	6		x	11	1,25
25053 re	3	2	3	x		13	0,95
24993 li	3,5	2	4	x			0,93
24993 re	4,5	2,5	5	x			1,13
25067 li	2,5	5,5	5		x	10	1,43
25067 re	3	3	3	x	x	12,5	0,85
25007 li	4	2,5	4	x			0,84
25007 re	5,5	1,5	5	x			1,08
25034 li	2	6	5		x	10,5	1,71
25034 re	2,5	3	3		x	11,5	0,77
24974 li	4,5	2	5	x			0,89
24974 re	3	1,5	3	x			0,85
25041 li	2	4	4		x	9,5	1,36
25041 re	2,5	2	3	x		12	0,74
24981 li	5	2,5	5	x			0,98
24981 re	3,5	2,5	4	x			0,91
25051 li	2	5,5	5		x	9,5	1,1
25051 re	2,5	4,5	4		x	13	0,76
24991 li	4	2	4	x			0,69
24991 re	3	3	3	x	x		1,0
25033 li	2,5	4	4		x	10	1,47
25033 re	2	1,5	2	x		12	0,95
24973 li	4	1,5	4	x			0,77
24973 re	3,5	1,5	4	x			0,97
25082 li	2	4,5	4		x	10,5	2,11
25082 re	2	3	3		x	13	0,94
25022 li	4	2	4	x		13	1,08
25022 re	3,5	2	4	x			0,93
25059 li	2	3	3		x	10	1,2
25059 re	3	6,5	6		x	9,5	1,46

Table 5: Main Data of Test Lubricants.

No.	Code No.	Nato Code	Brand Name	QPL. No.	Specification	kin. Viscosity at 100°C in mm^2/s	typical Ryder Gear Result in ppi
1	TEL-7041	0-117	Reference Oil C	-	-	18	2960*
2	-	-	Hercolube A	-	-	5	2260°
3	TEL-7038	0-148	Mobil RM-248A	15F-1	MIL-L-7808H	3	2500*
4	TEL-7039	0-148	Exxon T.O.2389	1M-1	MIL-L-7808H	3	2490*
5	TEL-7040	0-156	Mobil Jet RM-139A	0-1A	MIL-L-23699B	5	2800*
6	-	0-160	Shell Asto 555	8/83E	DERD 2497	5	4400°

* reported from H. Jones, WPAFB, USAF

° reported from A. Kling, WIM, German Army

Table 6: Load Stages of the FZG Ryder Test

* calibrated shaft No. S18/23 diameter 18 mm

Load Stage	Torque in Nm	Tooth Load in N/mm	Tooth Load in lb/in	Gauge Setting* in mm
1	17.5	66	375	0.33
2	35.0	131	750	0.66
3	52.5	197	1125	0.99
4	70.0	263	1500	1.32
5	87.5	329	1875	1.66
6	105.0	394	1250	1.99
7	122.5	460	2625	2.32
8	140.0	526	3000	2.65
9	157.5	591	3375	2.98
10	175.0	657	3750	3.31
11	192.5	723	4125	3.64
12	210.0	788	4500	3.97
13	227.5	854	4875	4.31
14	245.0	920	5250	4.64
15	262.5	985	5625	4.97
16	280.0	1051	6000	5.30

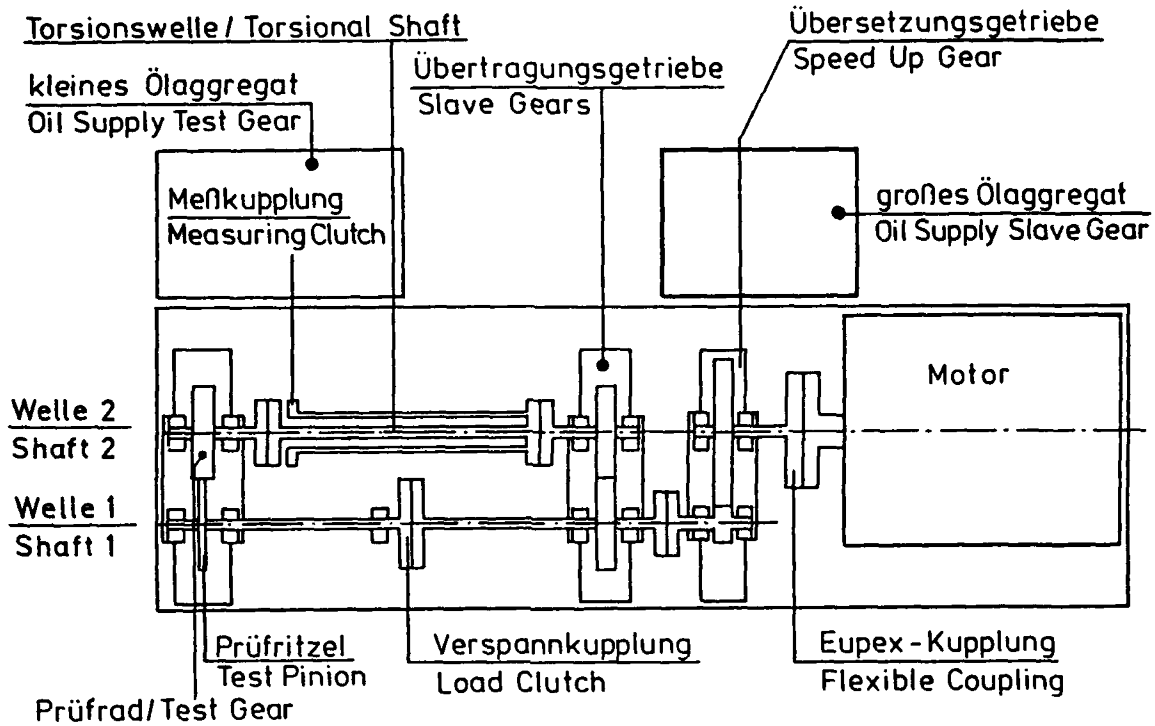


Fig. 1: FZG-Ryder Gear Test Rig (Schematic View)

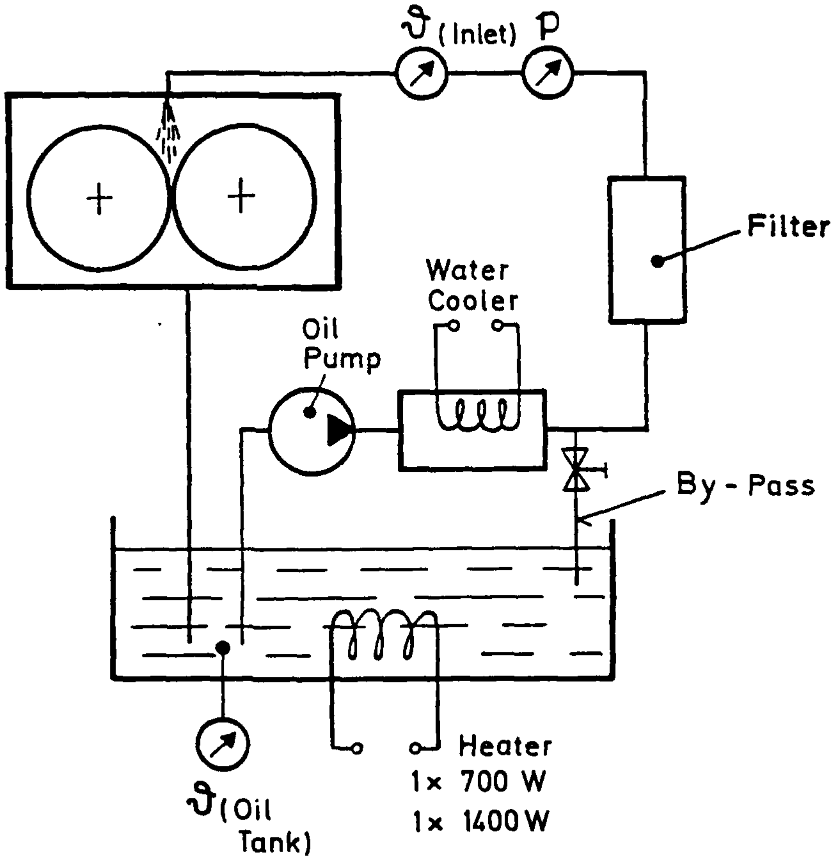


Fig. 2: Standard Oil Supply System (Schematic View)

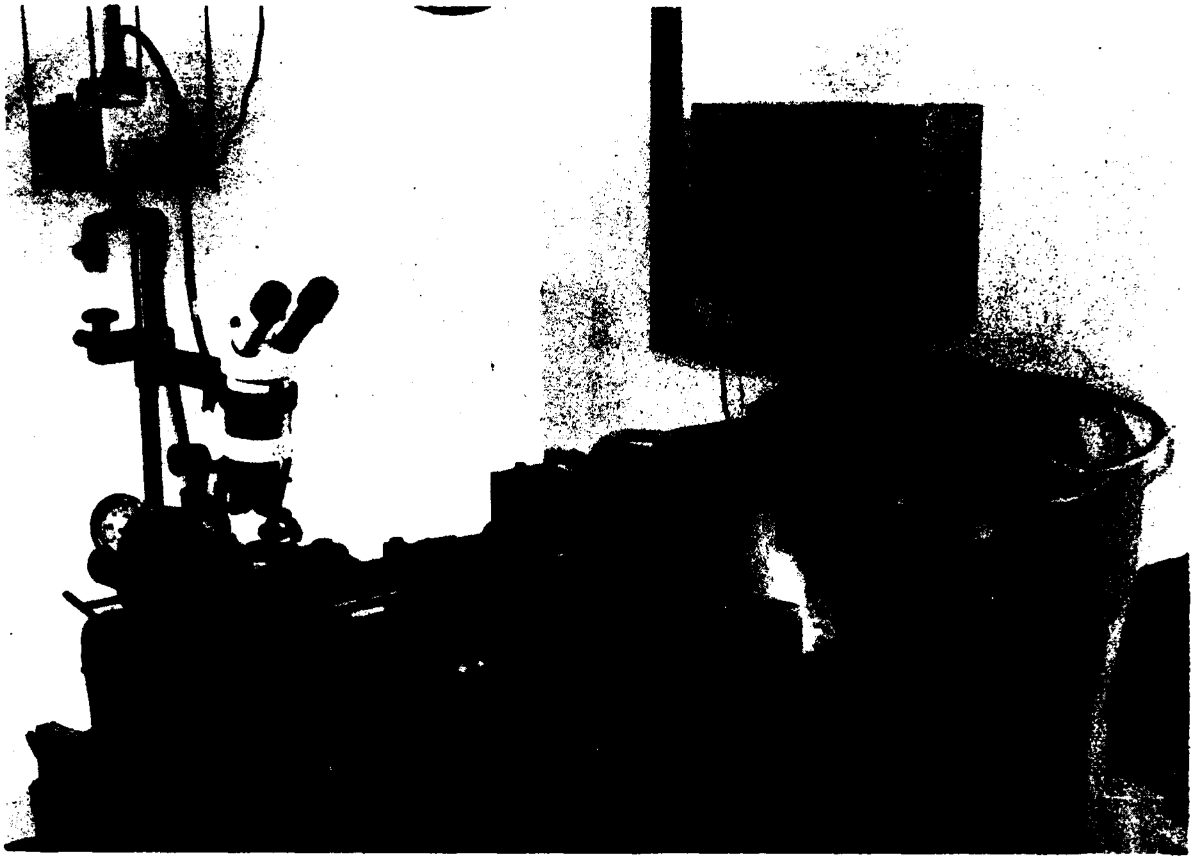


Fig. 3: Photo of the Standard FZG-Ryder Gear Test Rig

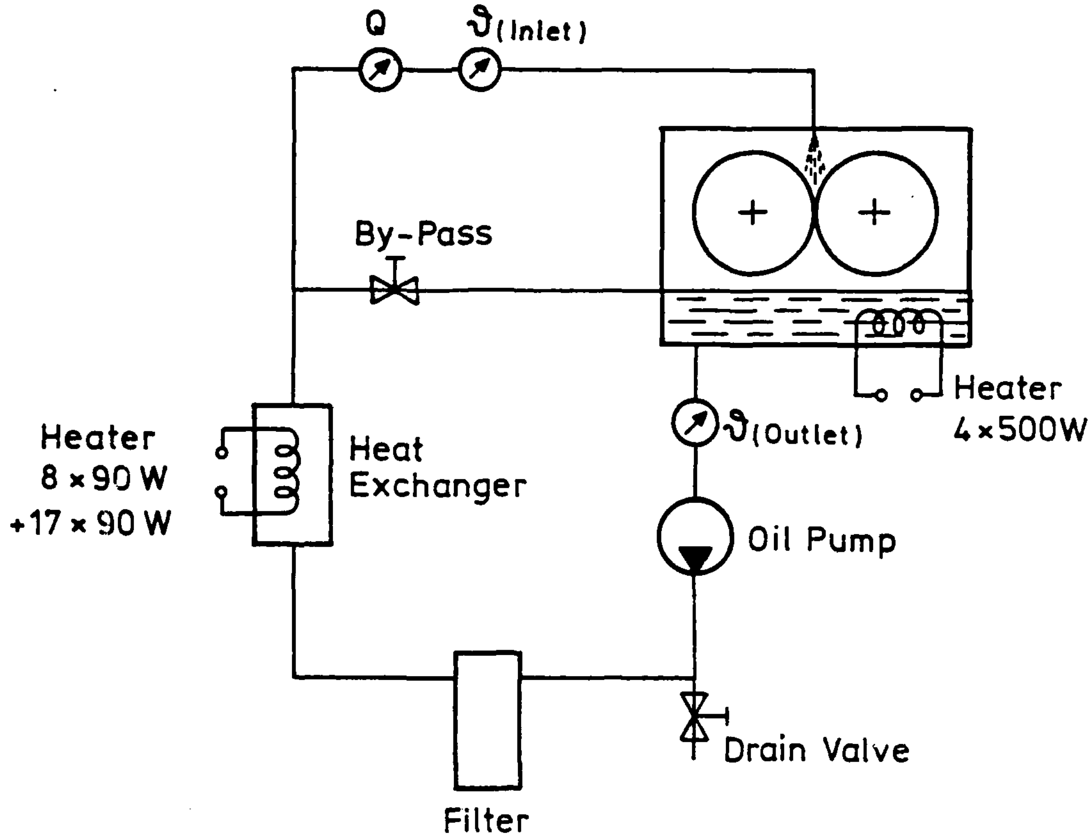


Fig. 4: High Temperature Test Oil Supply System

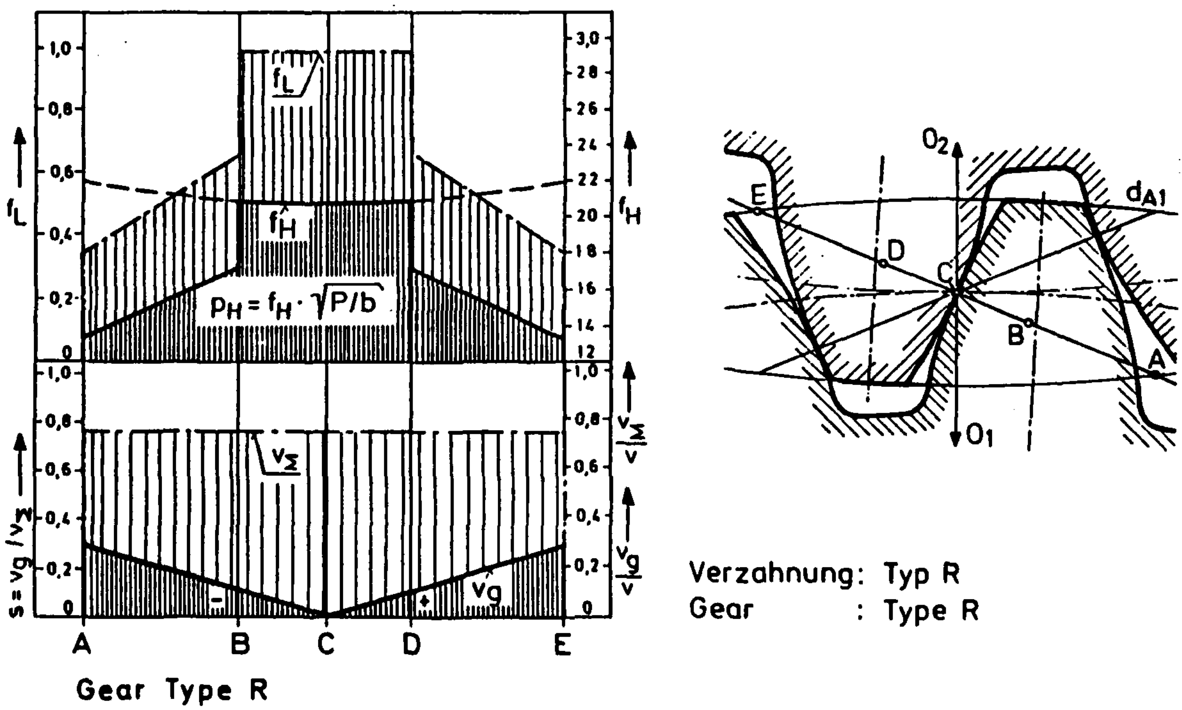
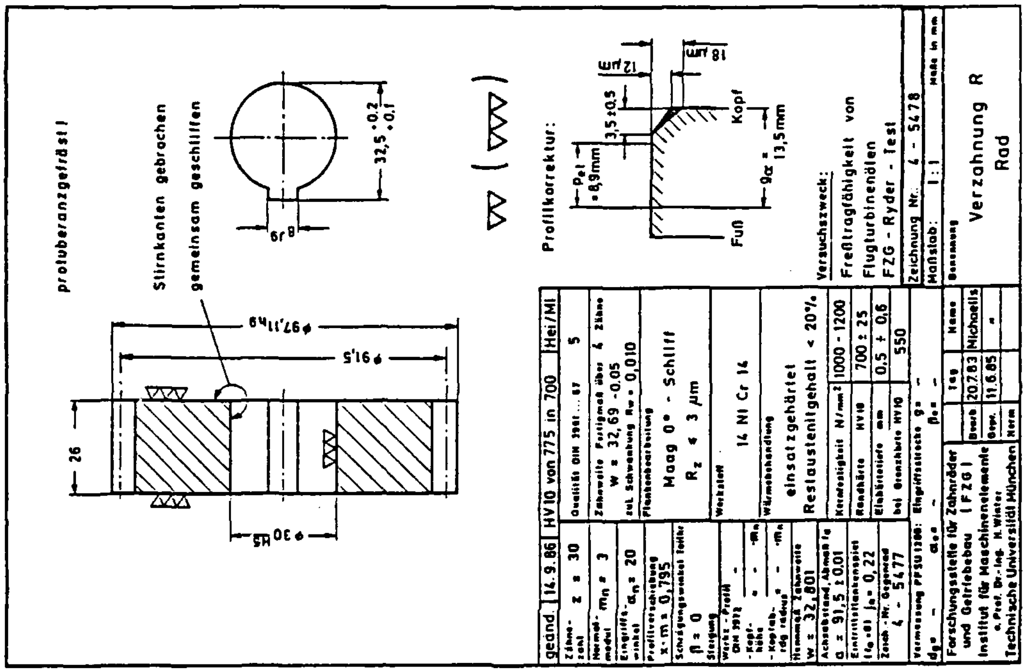


Fig. 5: Load and Speed Distribution (Gear Type R)



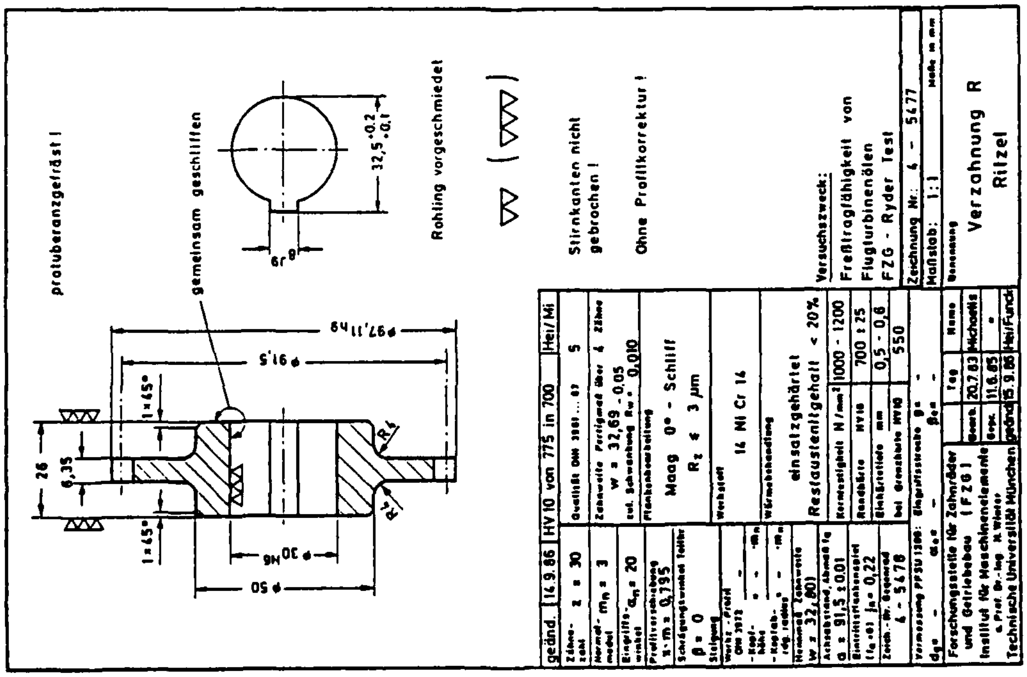
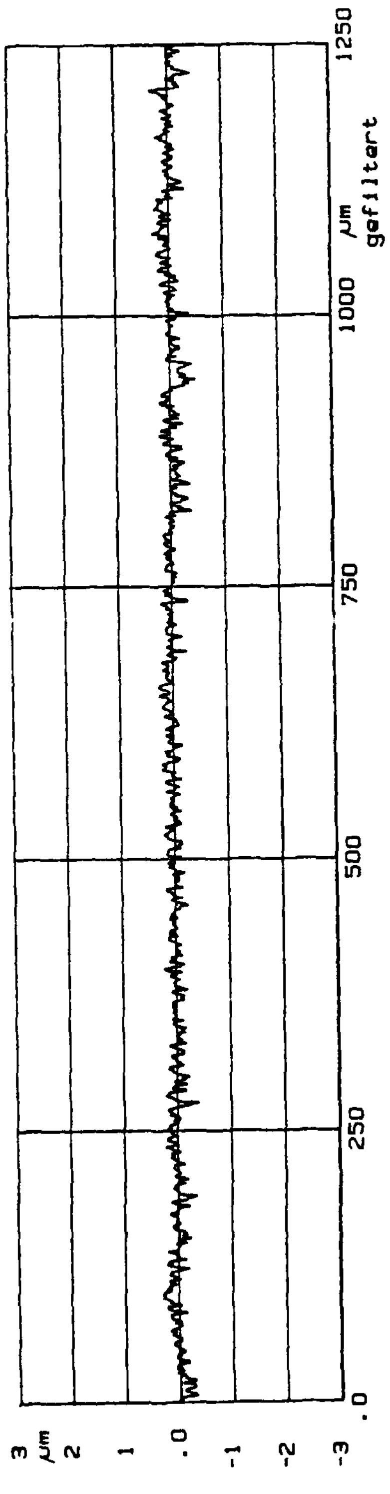


Fig. 6: Drawings of Test Gears Type R



Oberflaechenprofil

Datum: 18.05.87
Werkstueck Nr.: 24973
Taster: 250-2
Tastgeschw.: Vt = .1 mm/s
Messtrecke: lm = 1.25 mm
Filtertyp: Phas. Korr. Hochpass
Wellenlaenge LC = .25 mm

Ra	= .0905 µm	0.0823	0.1335
Rt	= .7888 µm	0.7389	1.432
Rz (DIN)	= .6495 µm	0.6007	1.085
	II li	III li	I li

Oberflächenprofil	roughness profile
Datum	date
Werkstück Nr.	sample number
Taster	stylus
Tastgeschwindigk.	sampling speed
Messtrecke	test length
Filtertyp	type of filter
Phos. Korr.Hochpass	inphase high pass filter
Wellenlänge	cut-off
R_a	arithmetic roughness (CLA)
R_t	peak-to-valley roughness
R_z (DIN)	mean peak-to-valley roughness
gefiltert	filtered

Fig. 7: Surface Roughness of Test Gears Type R (Example)

Messprotokoll	accuracy measurement sheet
Flankenform	tooth profile form
Flankenrichtung	lead
Teilung	base pitch
Ritzel	pinion
Rad	gear
Evolvente	involute
Zahnbreite	tooth width
Linksflanke	left hand flank
Rechtsflanke	right hand flank
Fuß	tooth root
Kopf	tooth tip
oben	top
unten	bottom

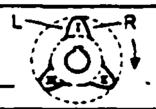
FZG Technische Universität Arcisstraße 21 8000 München 2

PROFESSOR DR.-ING. HANS WINTER

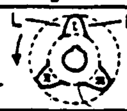
MESSPROTOKOLL

Flankenform – Flankenrichtung – Teilung

Ritzel ME 24973

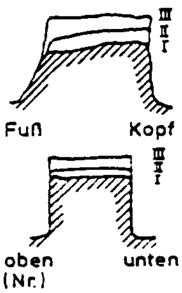


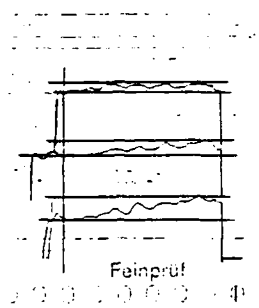
Rad ME ________

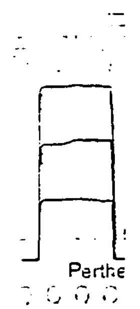


↑ V =	Evolvente → V = 2 : 1	Zahnbreite → V = 2 : 1

Linksflanke L

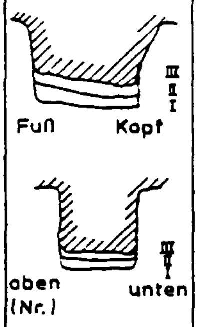


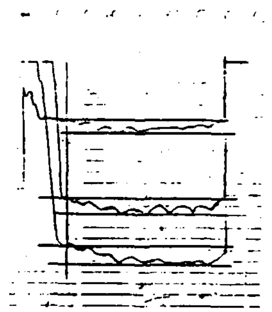


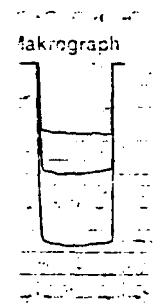


I / II / III	F_{α} =	4 µm	2,5 µm	1,5 µm	F_{β} =	< 2,5	µm
I / II / III	$f_{H\alpha}$ =				$f_{H\beta}$ =		
I / II / III	$f_{f\alpha}$ =				$f_{f\beta}$ =		

Rechtsflanke R

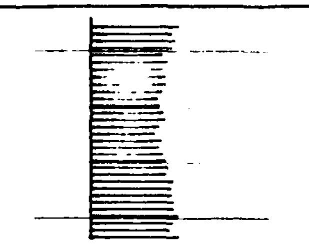


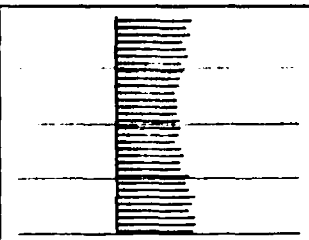




I / II / III	F_{α} =	3,5 µm	3 µm	2,5 µm	F_{β} =	< 2,5	µm
I / II / III	$f_{H\alpha}$ =				$f_{H\beta}$ =		
I / II / III	$f_{f\alpha}$ =				$f_{f\beta}$ =		

Teilung Linksflanke → 1000x Rechtsflanke





	Linksflanke		Rechtsflanke
f_{pmax} =		f_{pmax} =	
f_{umax} =	1,5 µm	f_{umax} =	1,5 µm
F_{pmax} =		F_{pmax} =	

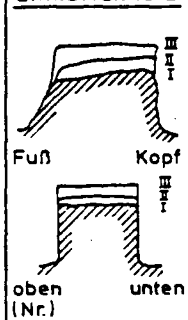
Datum: ________ Sachbearbeiter: ________ Projekt Nr.: ________

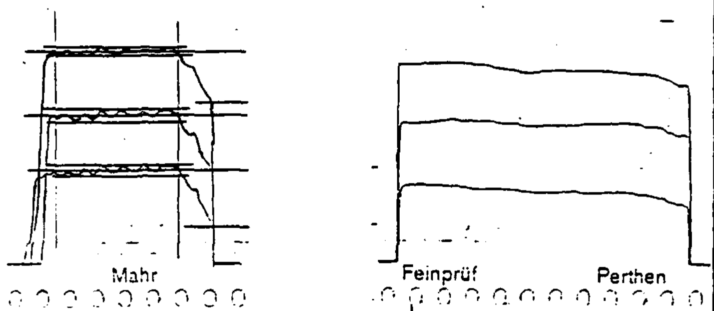
Fig. 8: Gear Quality Measurement of Test Pinion Type R (Example)

FZG Technische Universität Arcisstraße 21 8000 München 2 PROFESSOR DR.-ING. HANS WINTER	**MESSPROTOKOLL** Ritzel ME ________ L R	Flankenform – Flankenrichtung – Teilung Rad ME 25033 L R

↑ V =	Evolvente → V = 2 : 1	Zahnbreite → V = 2 : 1

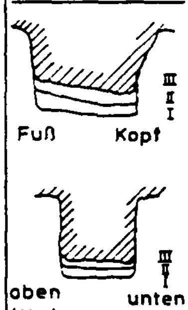
Linksflanke L

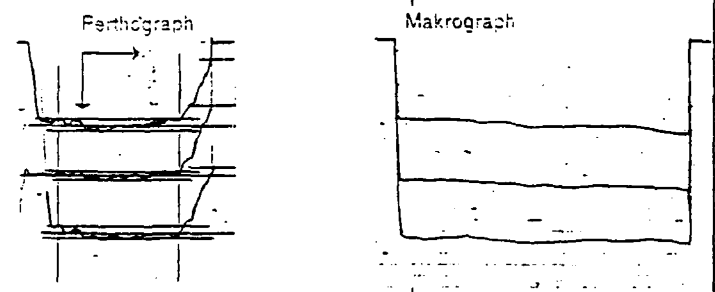




I / II / III	F_α =	2 µm	2,5 µm	1,5 µm	F_β =		< 2,5 µm
I / II / III	$f_{H\alpha}$ =				$f_{H\beta}$ =		
I / II / III	$f_{f\alpha}$ =				$f_{f\beta}$ =		

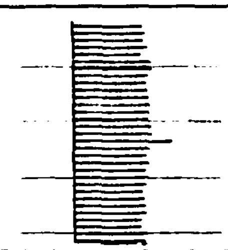
Rechtsflanke R

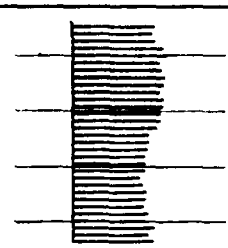




I / II / III	F_α =	2 µm	1,5 µm	2 µm	F_β =		< 2,5 µm
I / II / III	$f_{H\alpha}$ =				$f_{H\beta}$ =		
I / II / III	$f_{f\alpha}$ =				$f_{f\beta}$ =		

Teilung Linksflanke → 1000x Rechtsflanke

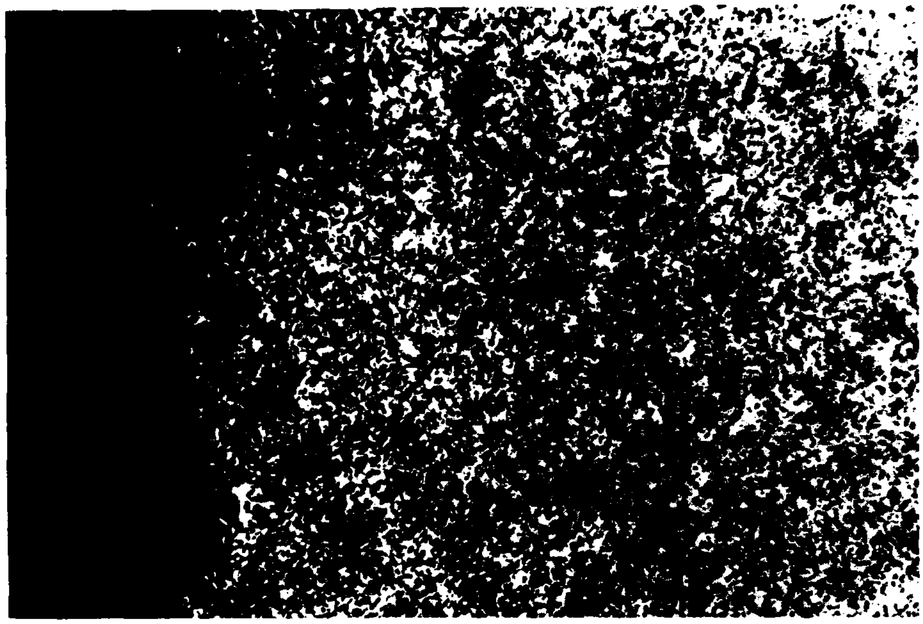




	Linksflanke		Rechtsflanke
f_{pmax} =		f_{pmax} =	
f_{umax} =	4 µm	f_{umax} =	1,5 µm
F_{pmax} =		F_{pmax} =	

Datum: ________ Sachbearbeiter: ________ Projekt Nr.: ________

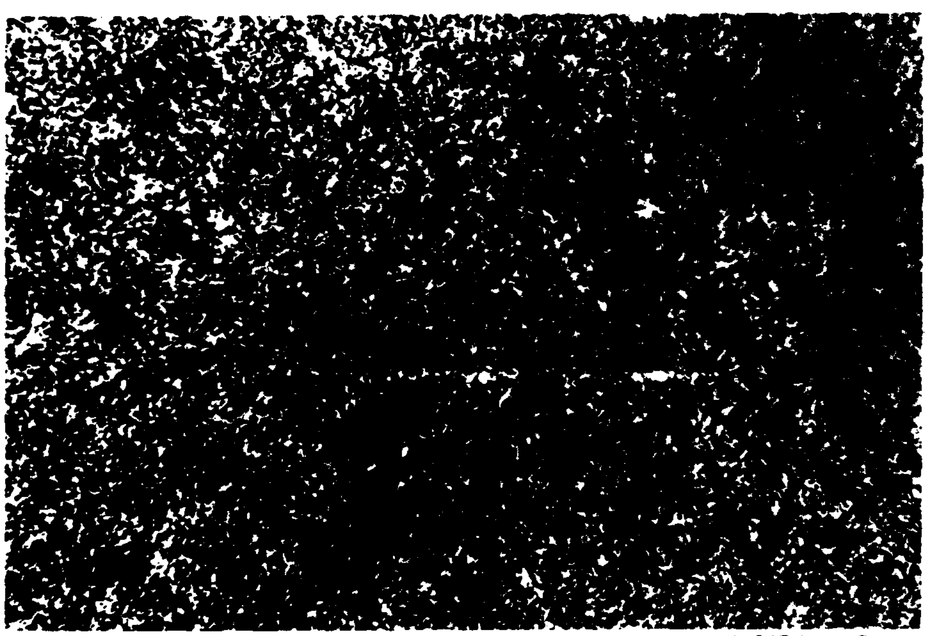
Fig. 9: Gear Quality Measurement of Test Gear Type R (Example)



31017/45 4

Case close to surface V = 200 x

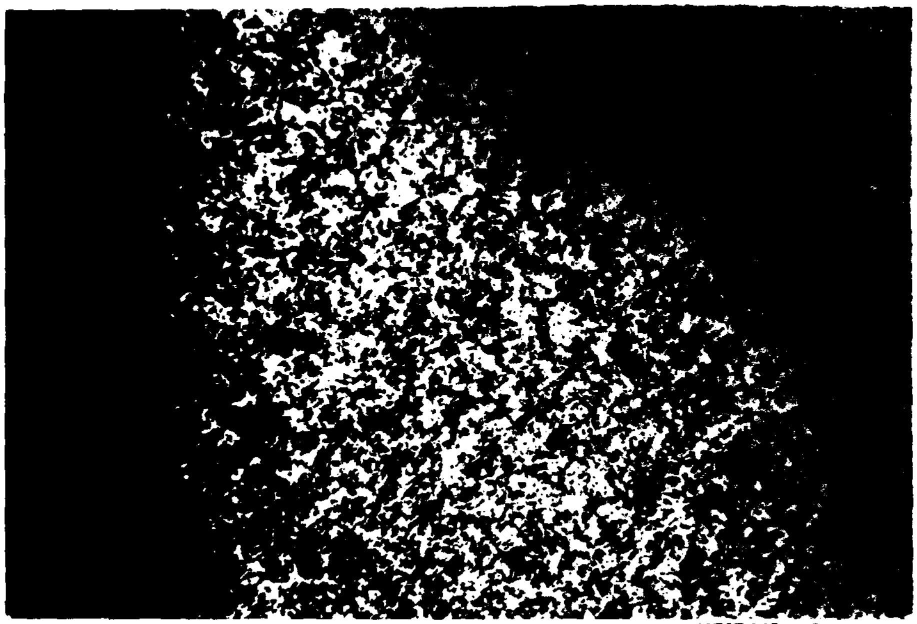
Structure: Tempered martensite with approx. 9 %
retained austenite



31017/43 5

Case in vicinity of surface V = 200 x

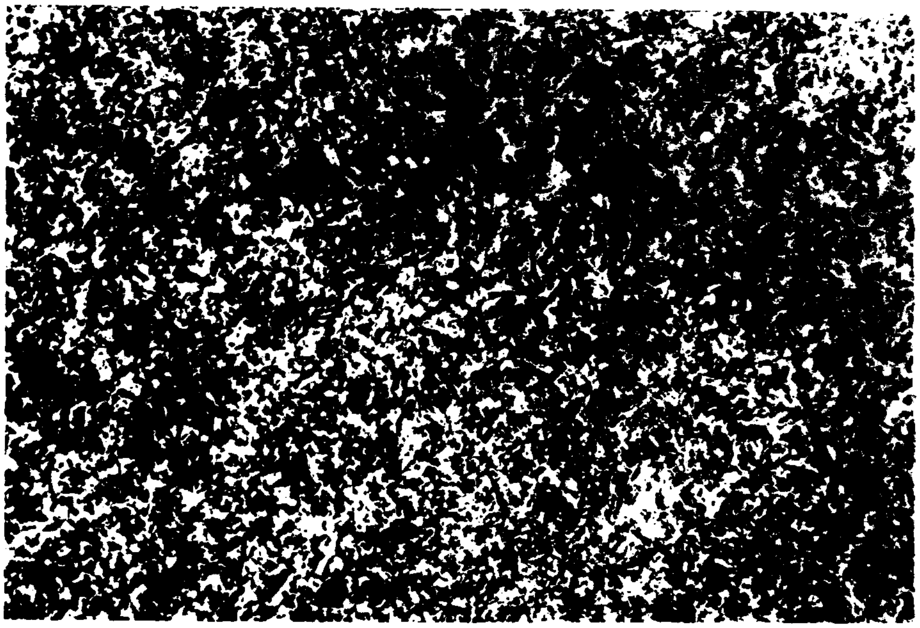
Fig. 10: Material Structure of Test Pinion Type R
(Example)



31017/49 2

Case close to surface V = 200 x

Structure: Tempered martensite with approx. 9 %
retained austenite



31017/47 3

Case in vicinity of surface V = 200 x

Fig. 11: Material Structure of Test Gear Type R
(Example)

Kleinlasthärtemessung HV 0,2 (n. DIN 50 190)
micro hardness measurement

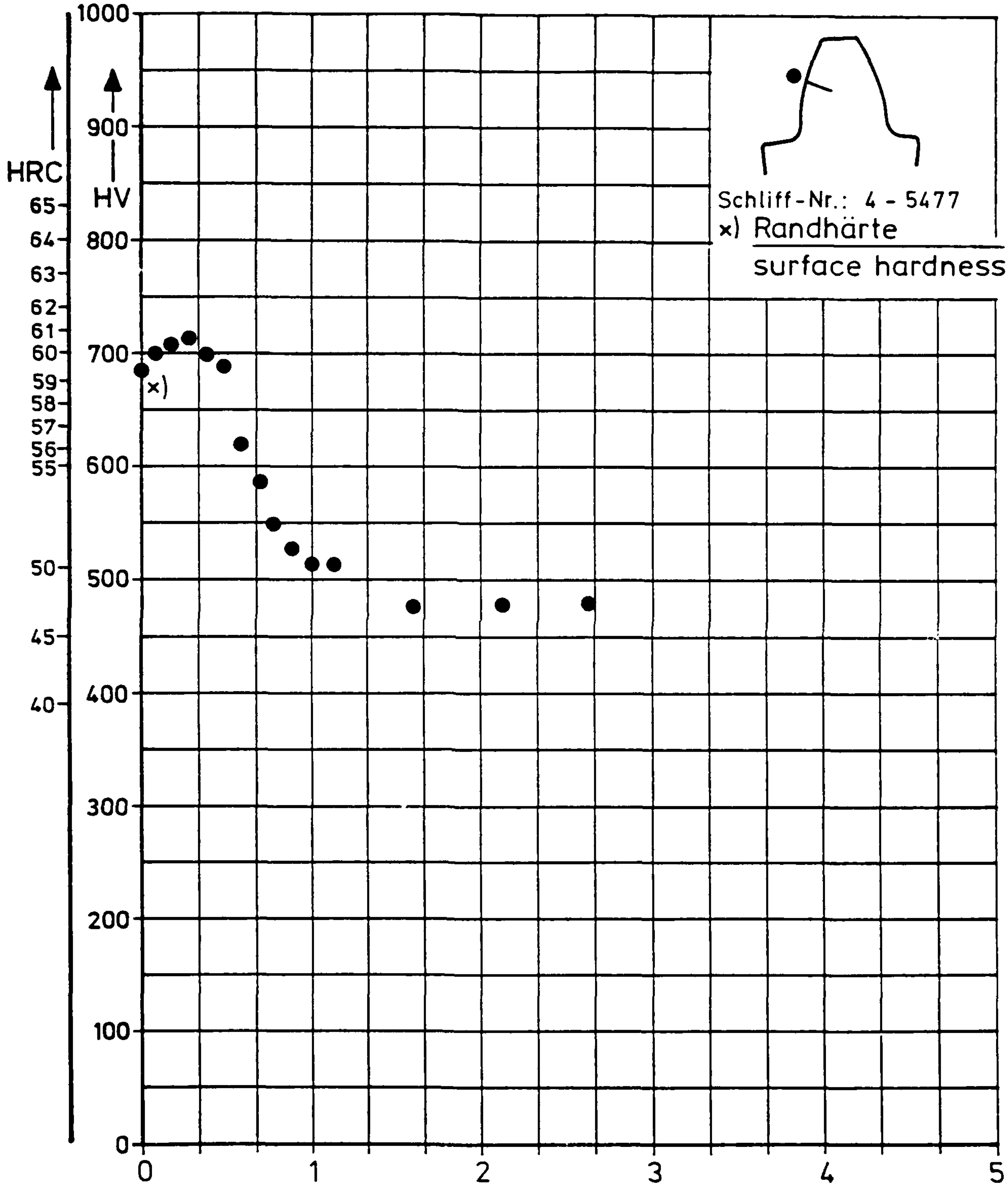


Fig. 12: Hardness Pattern of Test Pinion Type R (Example)

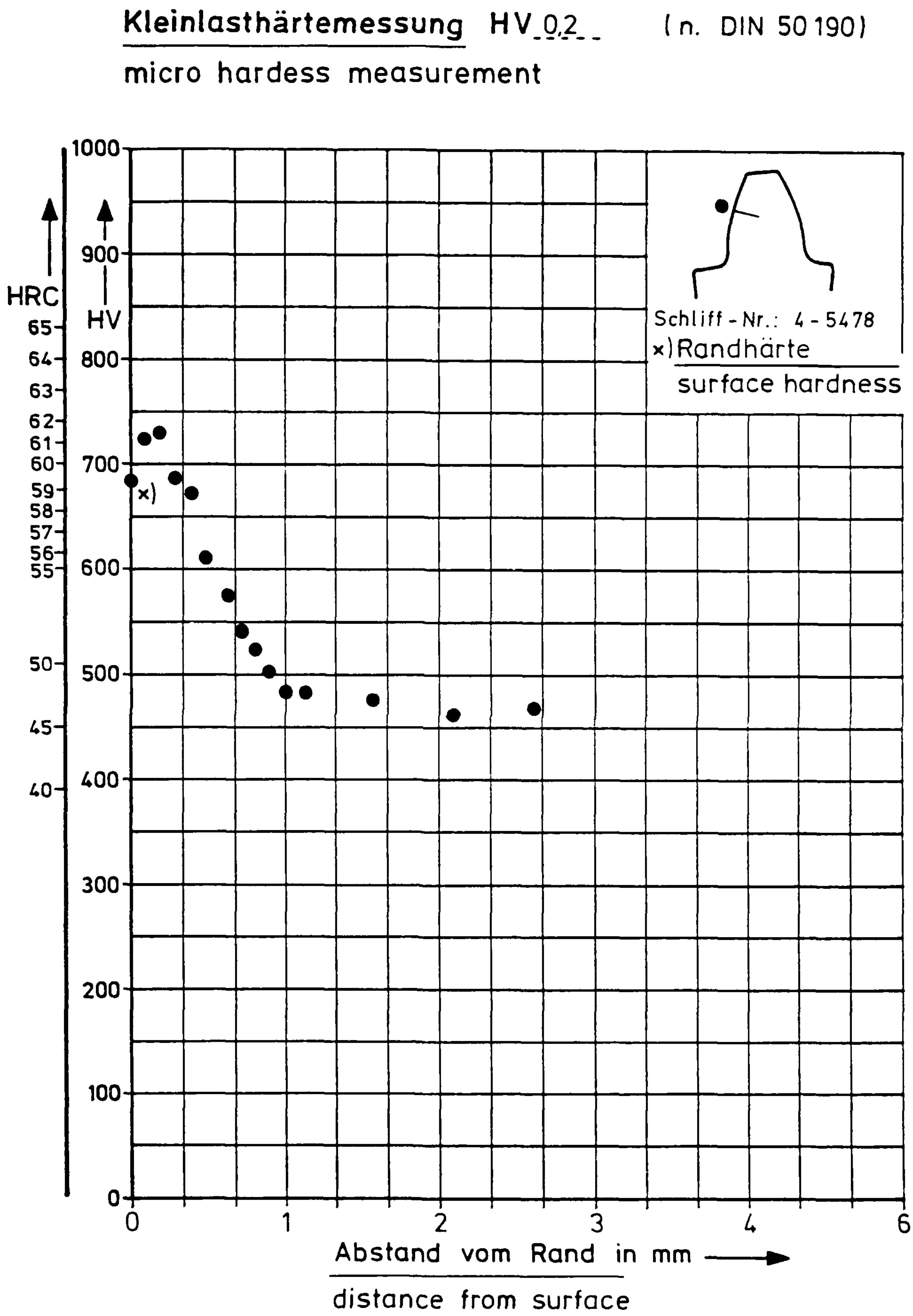


Fig. 13: Hardness Pattern of Test Gear Type R (Example)

Test Diagram

Load Stage $\boxed{9}$ Scuffed Area $\boxed{30{,}9\%}$ Signature $\boxed{\text{Funck}}$

$$\text{Scuffed Area} = \frac{\text{Total Failed Area } \boxed{185{,}5}}{\text{Total Flank Area } \boxed{600}} \cdot 100\,\% = \boxed{30{,}9\%}$$

Lubricant $\boxed{0 - 148}$ Date $\boxed{6.5.86}$

Tooth Flanks

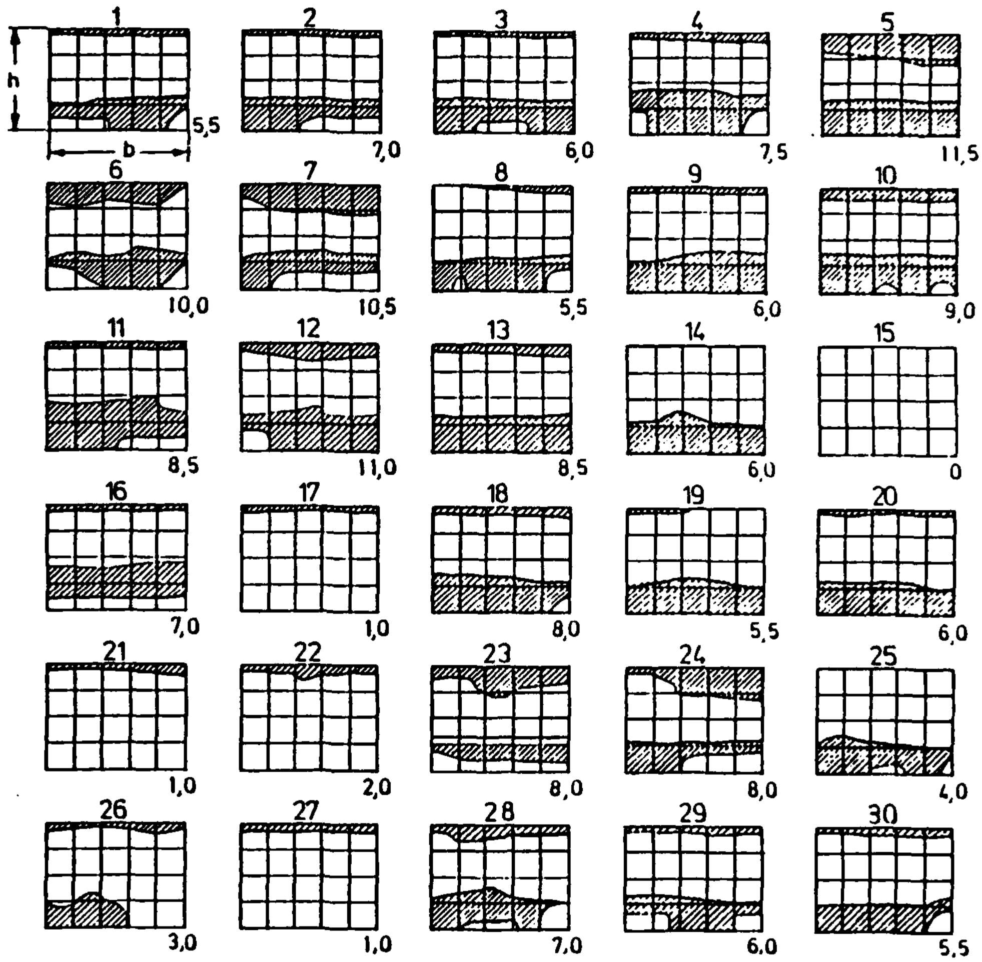


Fig. 14: Test Diagram for the Evaluation of the Scuffed Flank Area (Example)

Test Plot FZG-Ryder Test

Test No. : R 37 Date : 5.5.86 - 7.5.86

Lubricant : 0 - 148

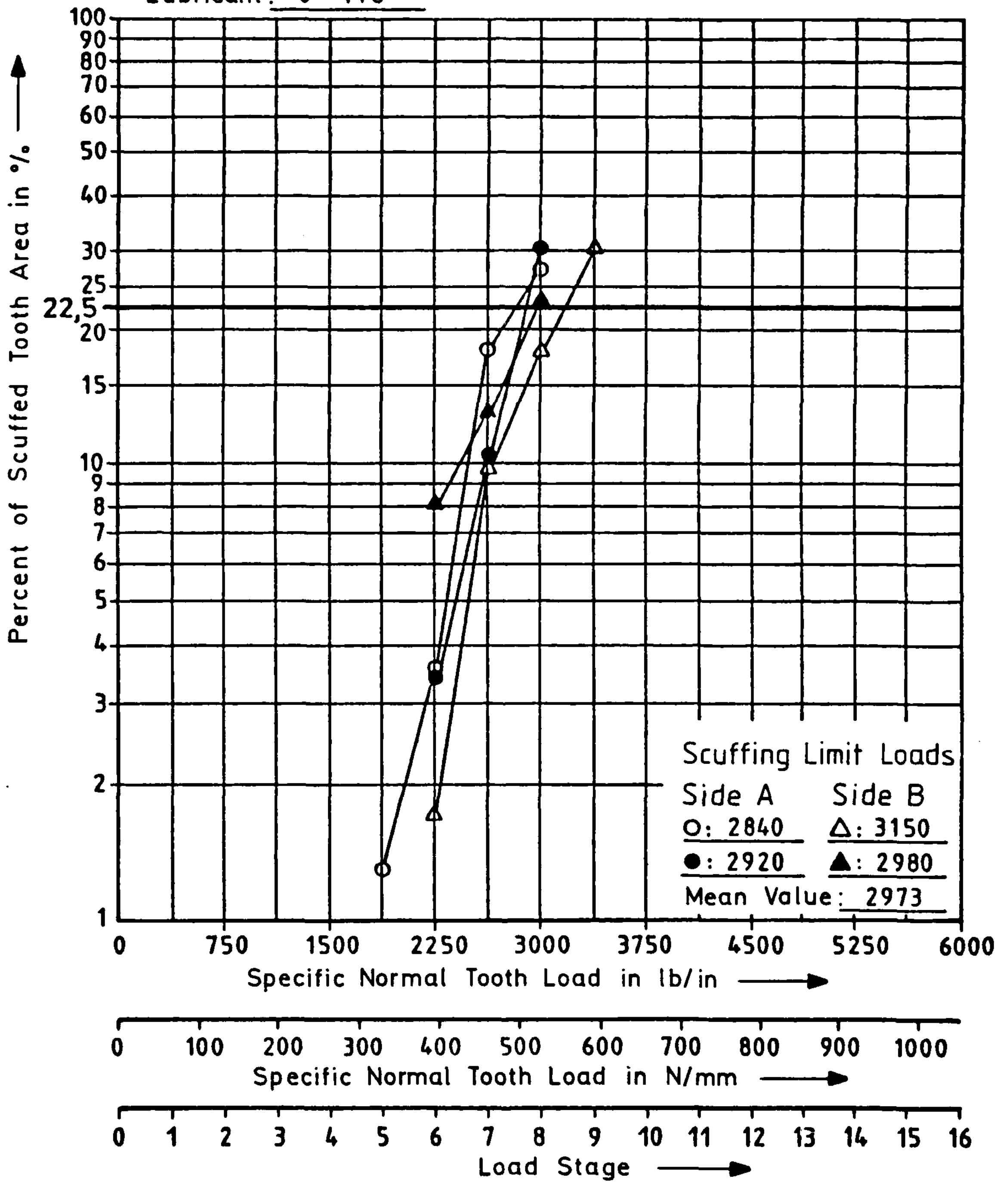


Fig. 15: Evaluation of Scuffing Load

GEAR TYPE R

SPRAY LUBRICATION WITH CONSTANT OIL TEMPERATURE
OF 74°C, OIL FLOW $\dot{V}$= 1,0 L/MIN.

PITCH LINE VELOCITY v = 46.5 M/S
DURATION PER LOAD STEP T = 10 MIN

LOAD STEPWISE INCREASED UNTIL SCORED
AREA ON THE PINION FLANK EXCEEDS APPR. 30%
OF ACTIVE FLANK

FAILURE CRITERION:
MORE THAN 22.5% OF ACTIVE FLANK AREA SCORED,
SCORING LOAD DETERMINED BY LINEAR INTERPOLATION

Fig. 16 : FZG-Ryder Test

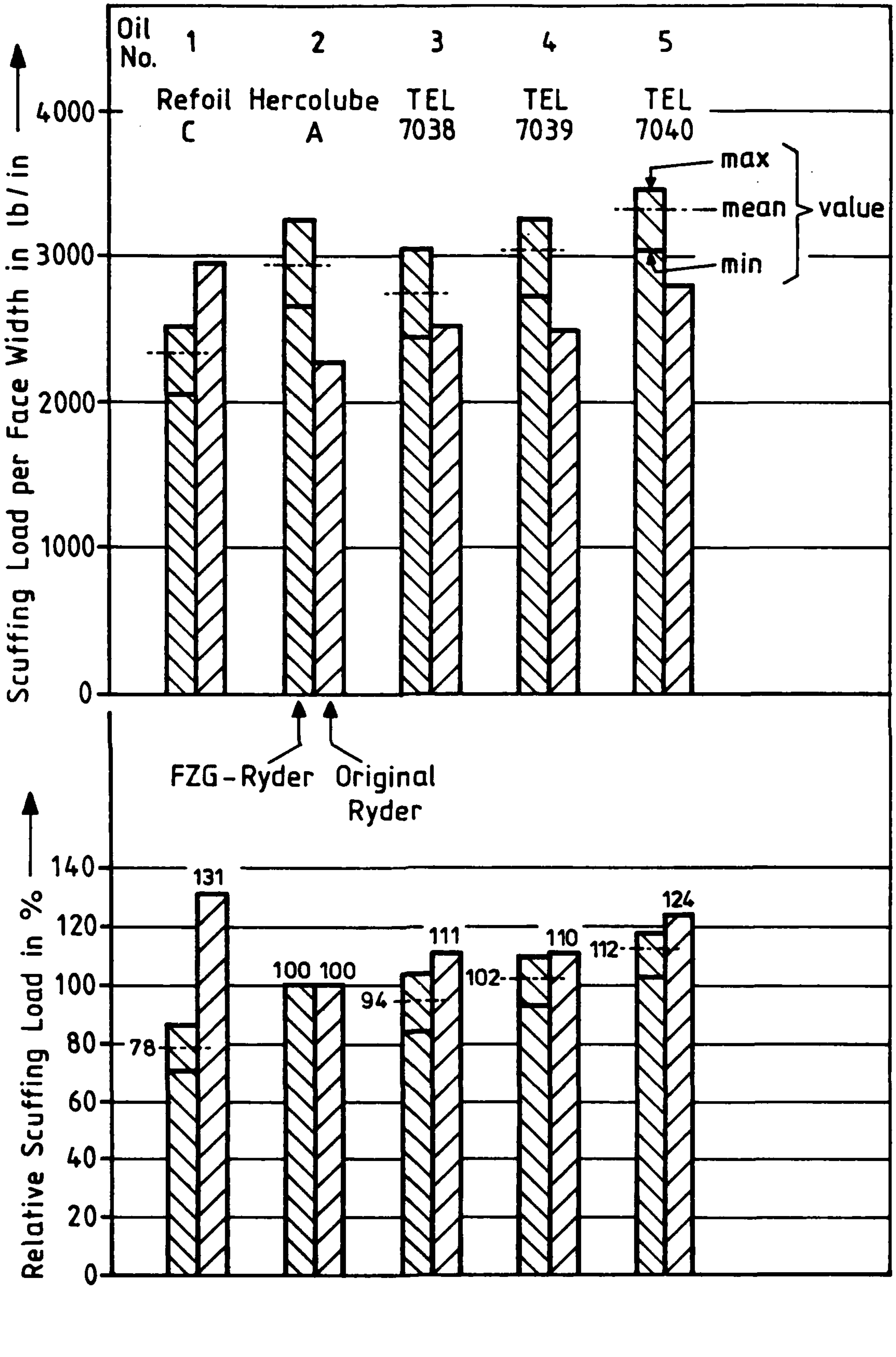


Fig. 17 : Comparison of FZG-Ryder and Original Ryder Results for Standard Conditions

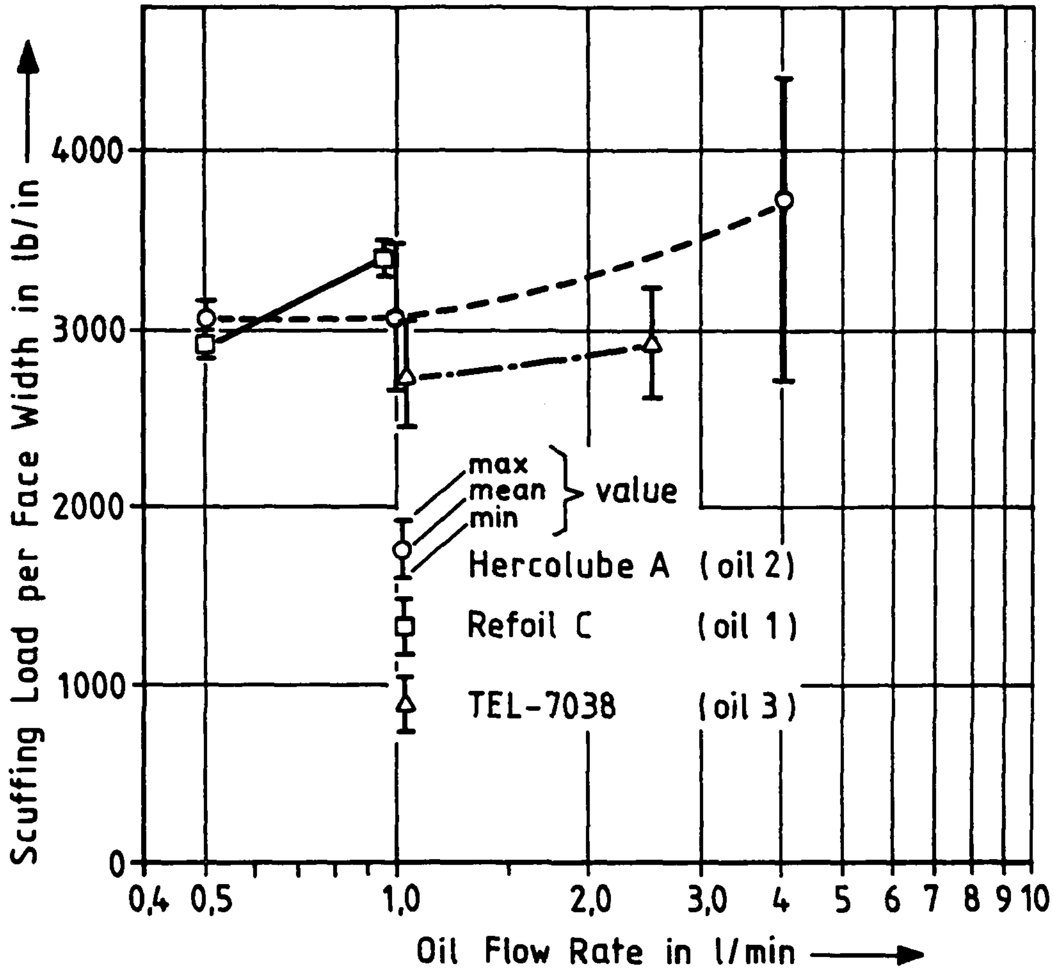


Fig. 18: Jnfluence of Oil Flow Rate on Scuffing Load

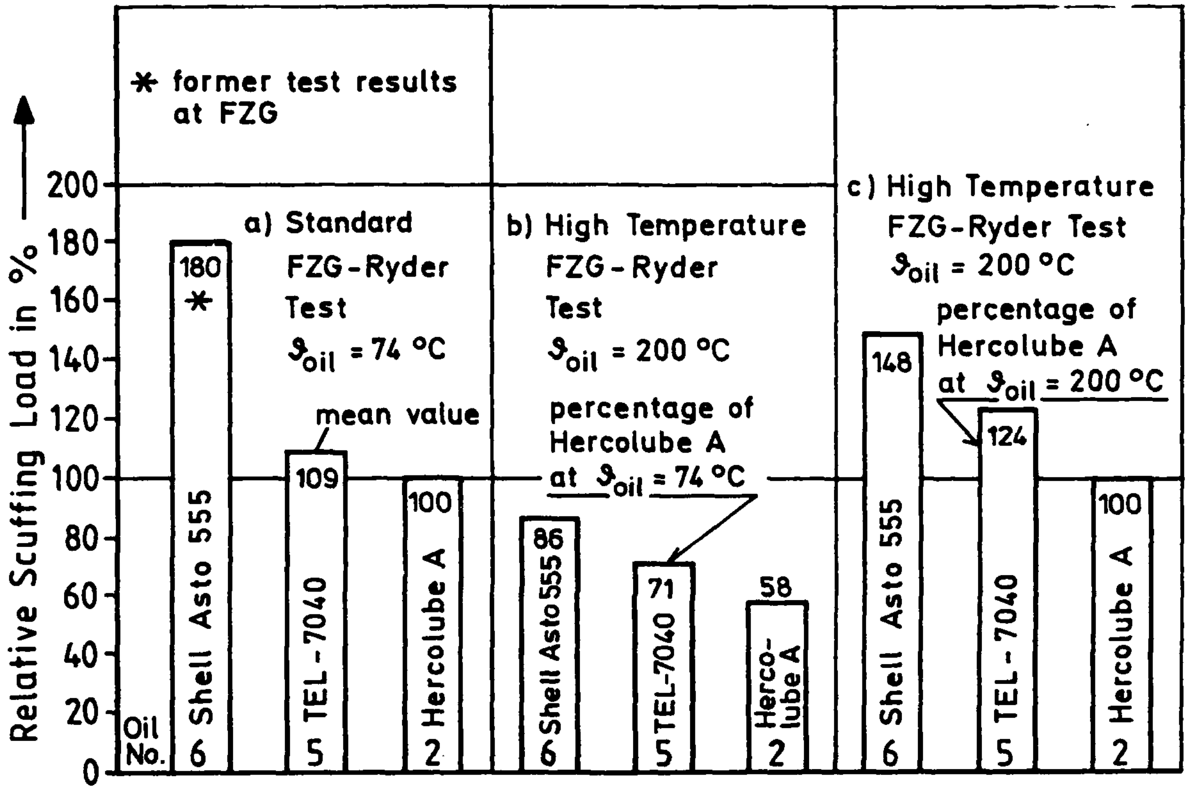
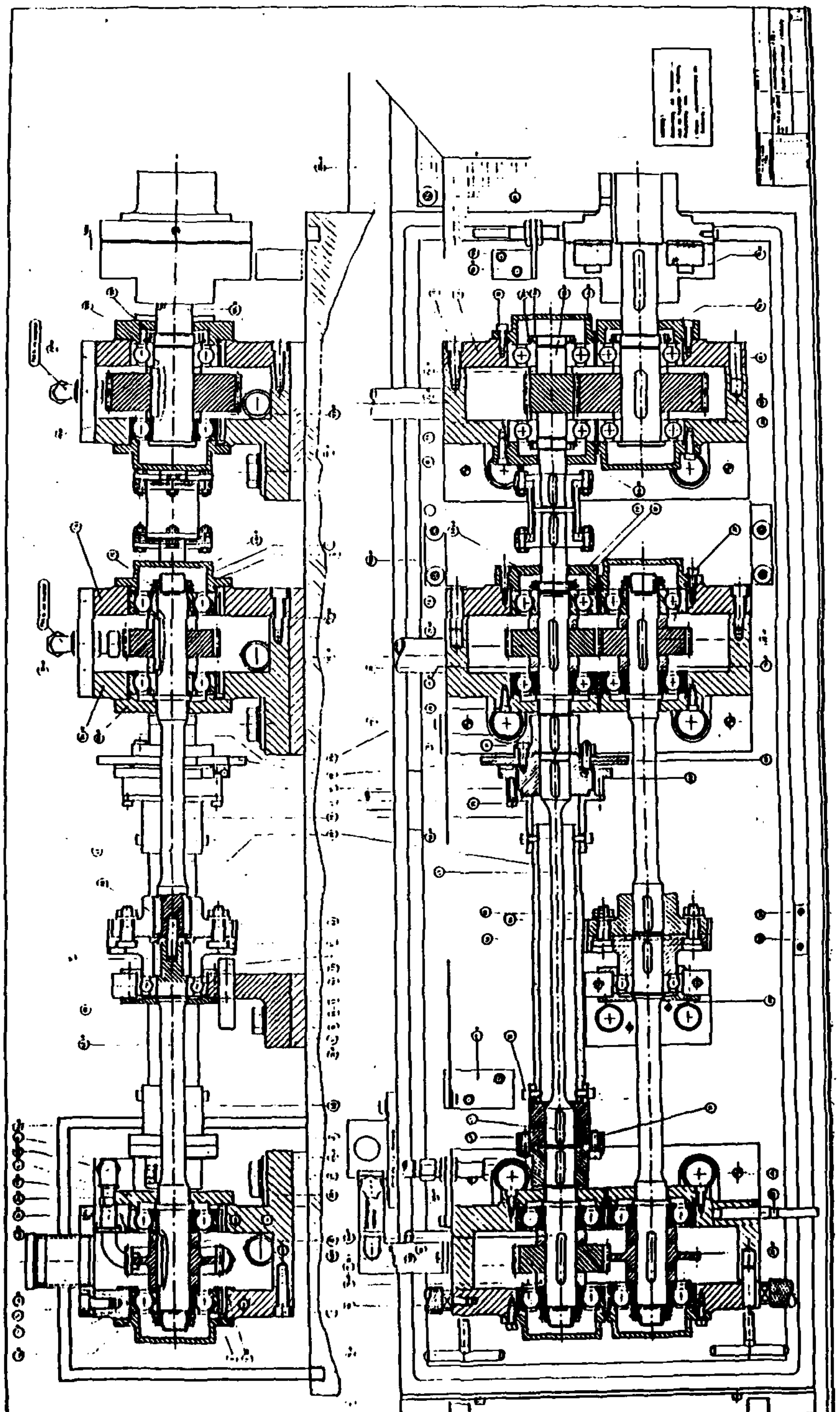


Fig. 19 : Relative Scuffing Load at Different Oil Jnlet Temperatures

Appendix A

FZG-Ryder Gear Test Rig Schematic



FZG-Ryder Test Rig

Appendix B

FZG-Ryder Test Results

(for english translation of graphs see Fig. 15)

FZG-Ryder Tests with Hercolube A

Oil Supply System: Standard

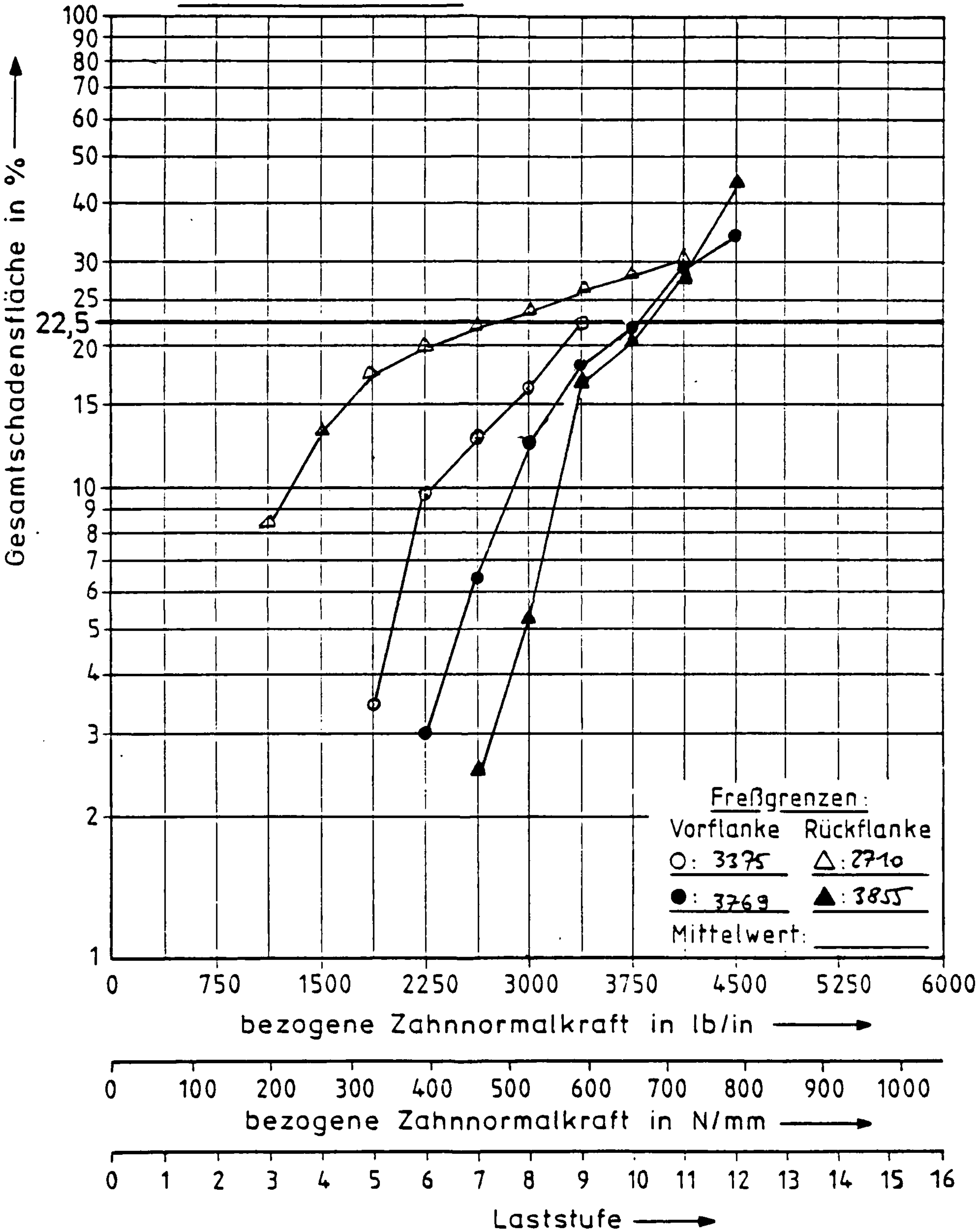
Lubricant Temperature: 74°C

Test No.	Date	Code Pinion	Code Gear	Flow Rate in l/min	Scoring Load F_{bt}/b in lb/in
1	13.7.87	24 964	25 024 ND	4	3375
2	8.9.87	24 964	25 024 NM	4	2710
3	9.9.87	24 986	25 046 ND	4	3769
4	10.9.87	24 986	25 046 NM	4	3855
5	11.9.87	24 974	25 034 ND	4	3927
6	14.9.87	24 998	25 058 ND	4	4399
7	15.9.87	24 998	25 058 NM	4	3991
8	15.9.87	24 980	25 040 ND	4	3825
	Tests No. 1 - 8:			Mean M =	3731 ppi
			Standard	Deviation S.D. =	500 ppi
19	25.9.87	24 993	25 053 ND	1	2769
20	28.9.87	24 993	25 053 NM	1	2865
21	28.9.87	25 000	25 060 ND	1	3237
22	29.9.87	25 000	25 060 NM	1	3223
23	29.9.87	24 971	25 031 ND	1	3059
24	30.9.87	24 971	25 031 NM	1	2652
	Tests No. 19 - 24:			M =	2968 ppi
				S.D. =	243 ppi

Versuchsprotokoll FZG - Ryder - Test

Test-Nr.: 1 – 4 Datum: 13.7. – 10.9.87

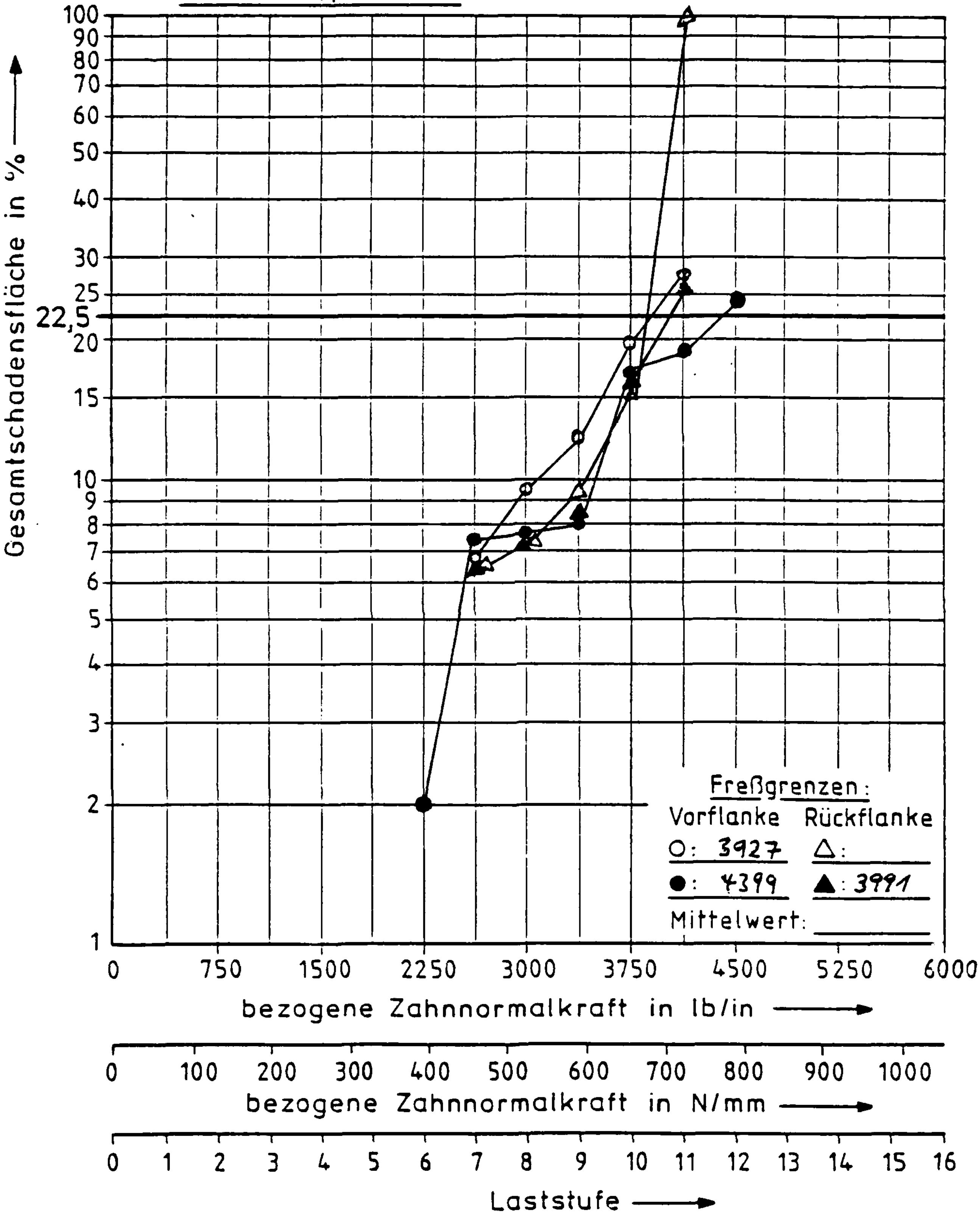
Öl: Hercolube A $\dot{V}$ = 4 l/min



Versuchsprotokoll FZG-Ryder-Test

Test-Nr.: 5-8 Datum: 11.9. - 15.9.87

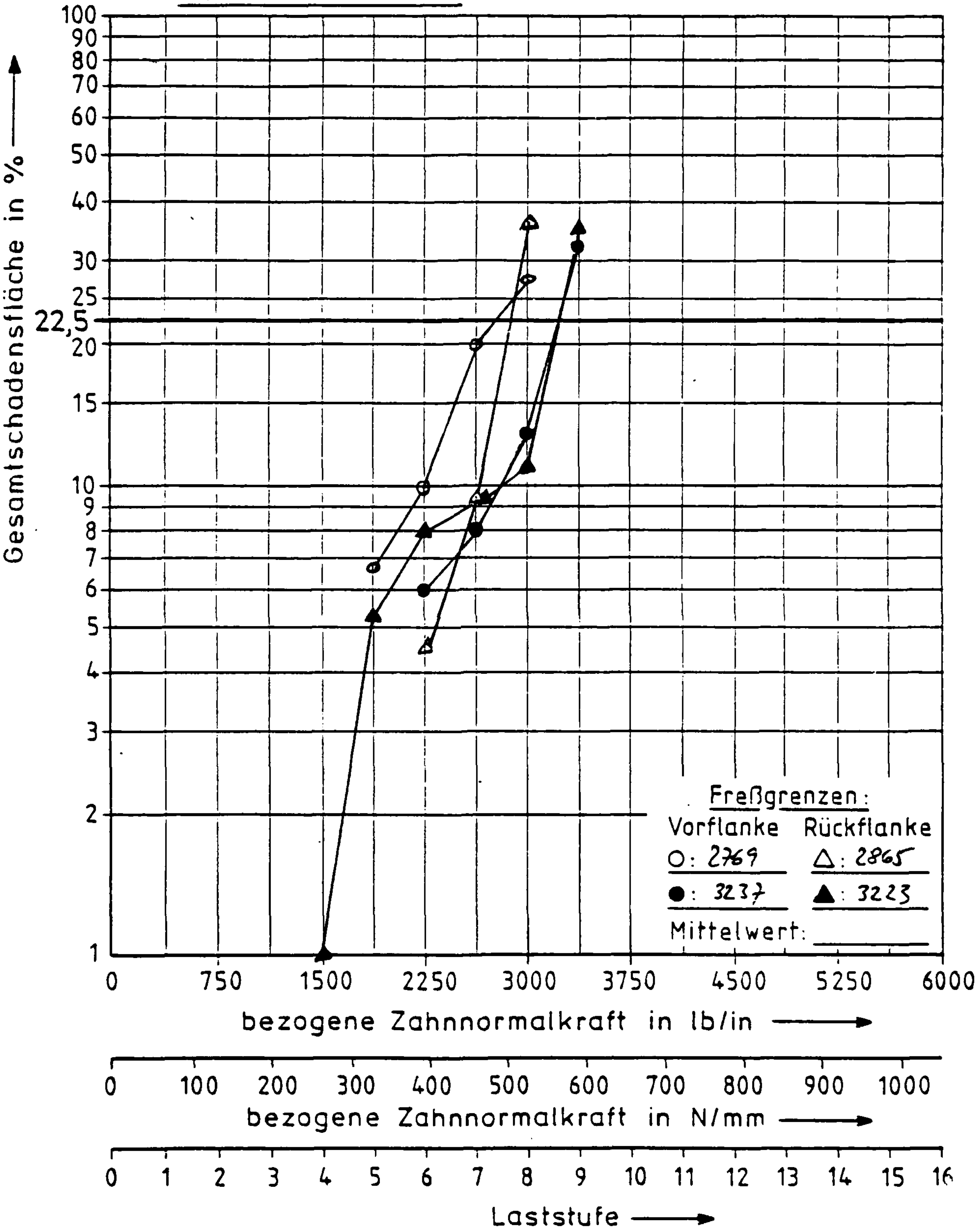
Öl: Hi-colube A $\dot{V}$ = 4 l/min.



Versuchsprotokoll FZG - Ryder - Test

Test-Nr.: 19 - 22 Datum: 25.9. - 29.9.87

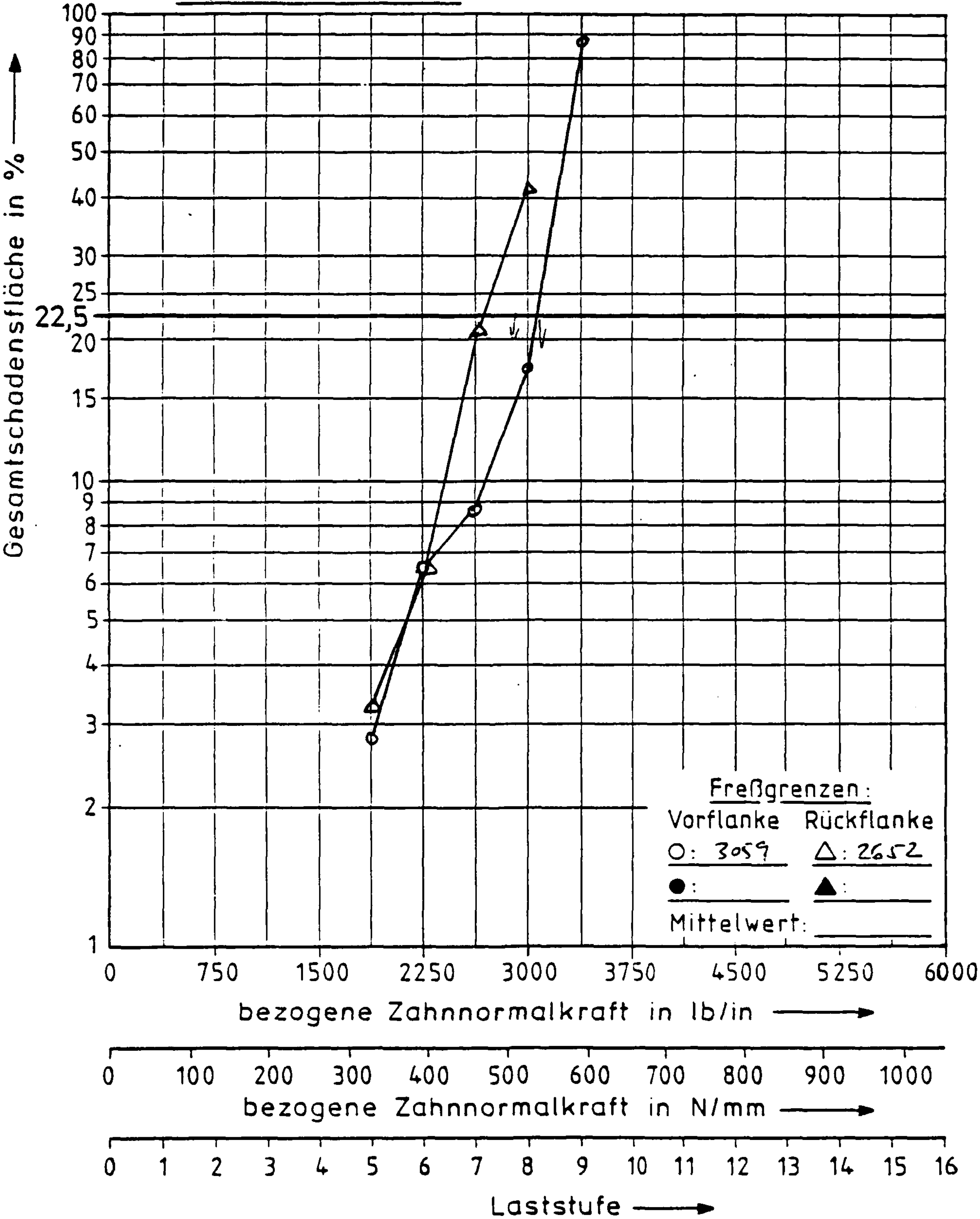
Öl: Hercolube A



Versuchsprotokoll FZG - Ryder - Test

Test - Nr.: 23 - 24 Datum: 29.9. - 30.9.87

Öl: Hercolube A



FZG-Ryder Tests with TEL 7038 0-148 Mobil

Oil Supply System: Standard

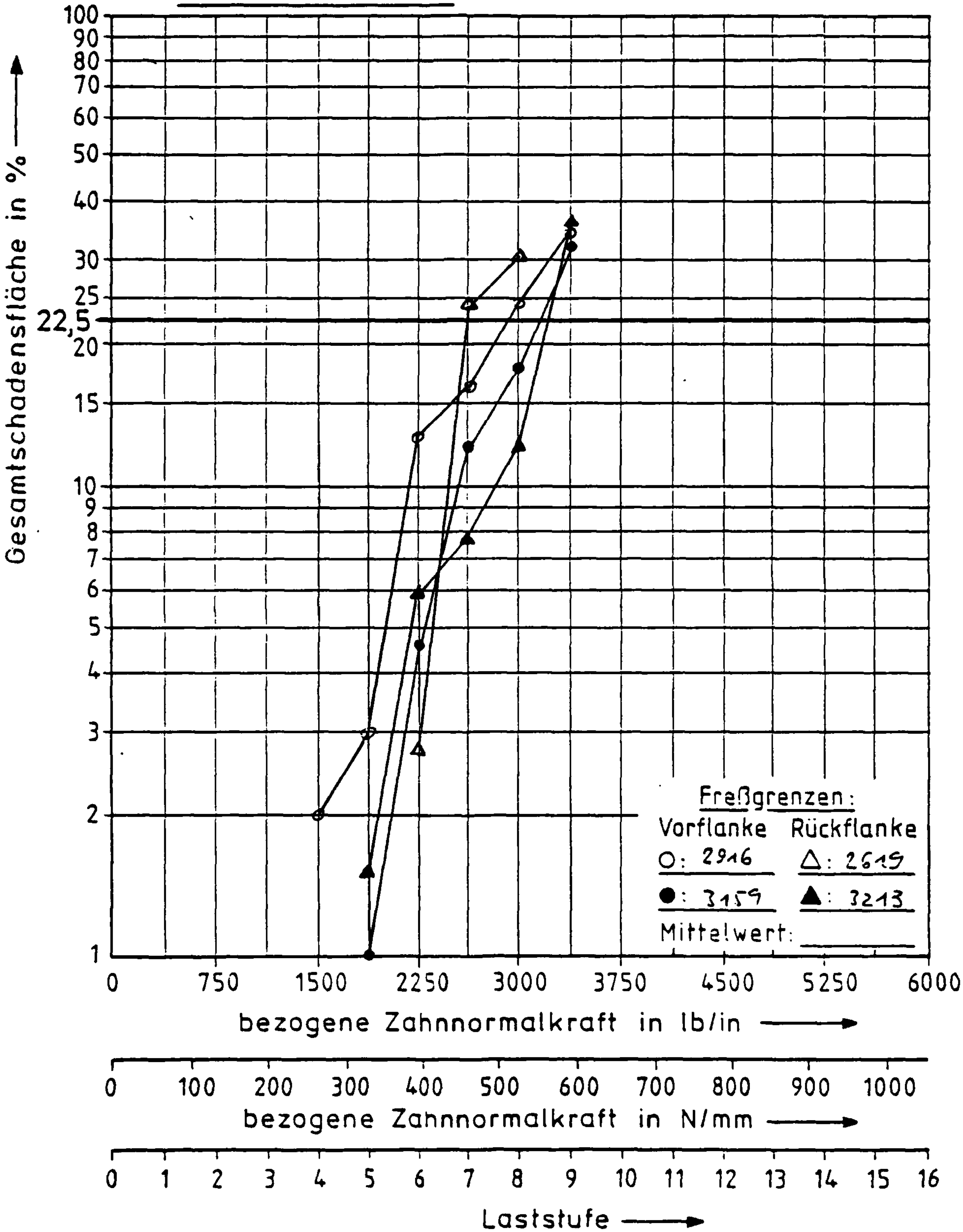
Lubricant Temperature: 74°C

Test No.	Date	Code Pinion	Code Gear	Flow Rate in l/min	Scoring Load F_{bt}/b in lb/in
9	16.9.87	24 991	25 051 ND	2,5	2916
10	17.9.87	24 991	25 051 NM	2,5	2619
11	17.9.87	24 972	25 032 ND	2,5	3159
12	18.9.87	24 972	25 032 NM	2,5	3213
	Tests No. 9 - 12:			M =	2977 ppi
				S.D. =	271 ppi
13	21.9.87	24 973	25 033 ND	1	2453
14	21.9.87	24 973	25 033 NM	1	2621
15	22.9.87	24 968	25 028 ND	1	2782
16	22.9.87	24 968	25 028 NM	1	2943
17	23.9.87	24 963	25 023 ND	1	3053
18	23.9.87	24 963	25 023 NM	1	2808
	Tests No. 13 - 18:			M =	2777 ppi
				S.D. =	216 ppi

Versuchsprotokoll FZG - Ryder - Test

Test-Nr.: 9 – 12 Datum: 16.9. – 18.9.87 $\dot{V} \approx 2{,}5\,l/min.$

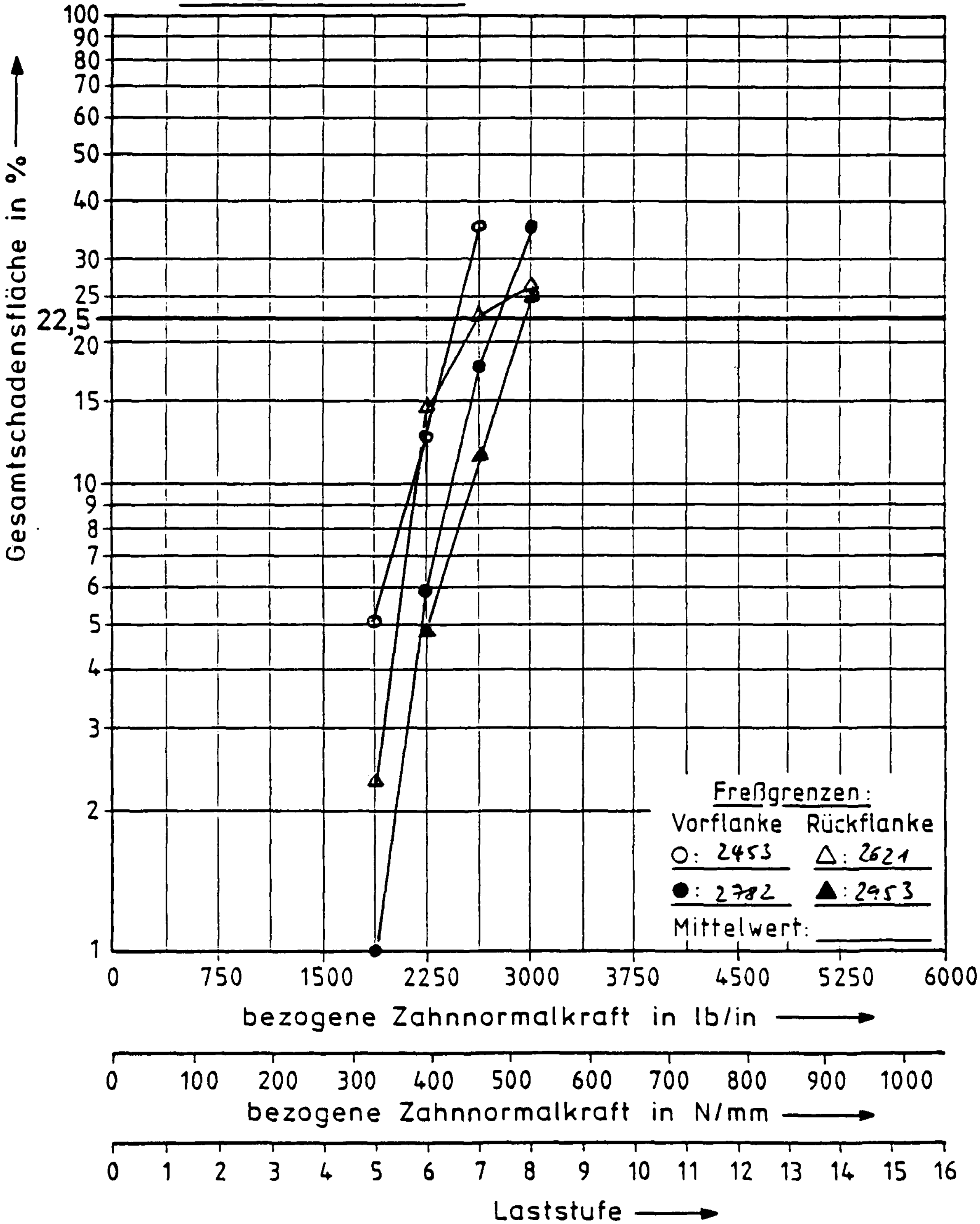
Öl: TEL 7038



Versuchsprotokoll FZG - Ryder - Test

Test-Nr.: 13 - 16 Datum: 21.9. - 22.9.87

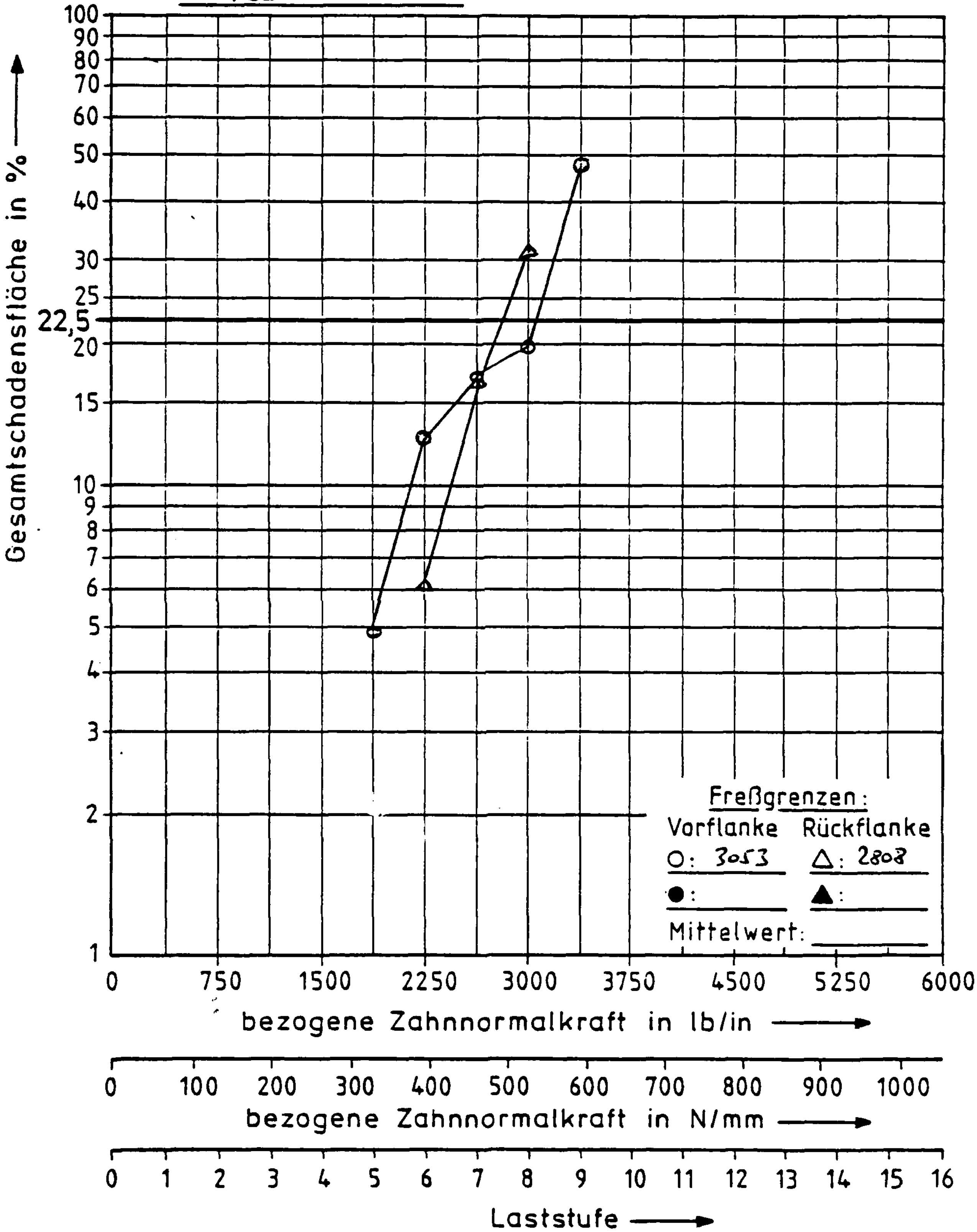
Öl: TEL 7038



Versuchsprotokoll FZG-Ryder-Test

Test-Nr.: 17 -18 Datum: 23.9.87

Öl: TEL 7038



FZG-Ryder Tests with TEL 7039 0-148 Exxon

Oil Supply System: Standard

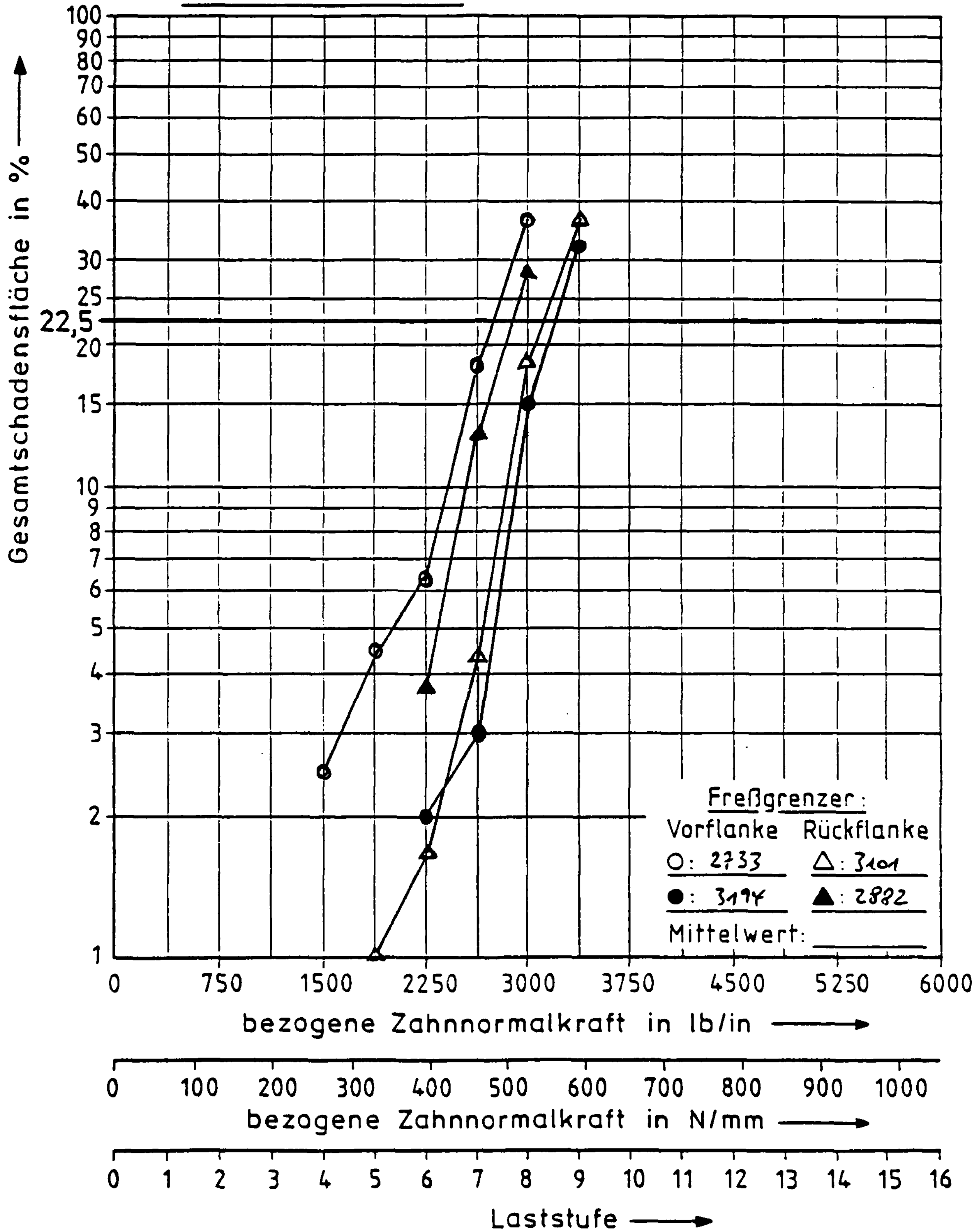
Lubricant Temperature: 74°C

Test No.	Date	Code Pinion	Code Gear	Flow Rate in l/min	Scoring Load F_{bt}/b in lb/in
33	8.10.87	24 078	25 038 ND	1	2733
34	9.10.87	24 078	25 038 NM	1	3101
35	12.10.87	24 996	25 056 ND	1	3194
36	12.10.87	24 996	25 056 NM	1	2882
37	13.10.87	24 985	24 045 ND	1	3246
38	13.10.87	24 985	24 045 NM	1	2936
39	14.10.87	24 995	25 055 ND	1	2943
40	14.10.87	24 995	25 055 NM	1	3207
				M =	3030 ppi
				S.D. =	184 ppi

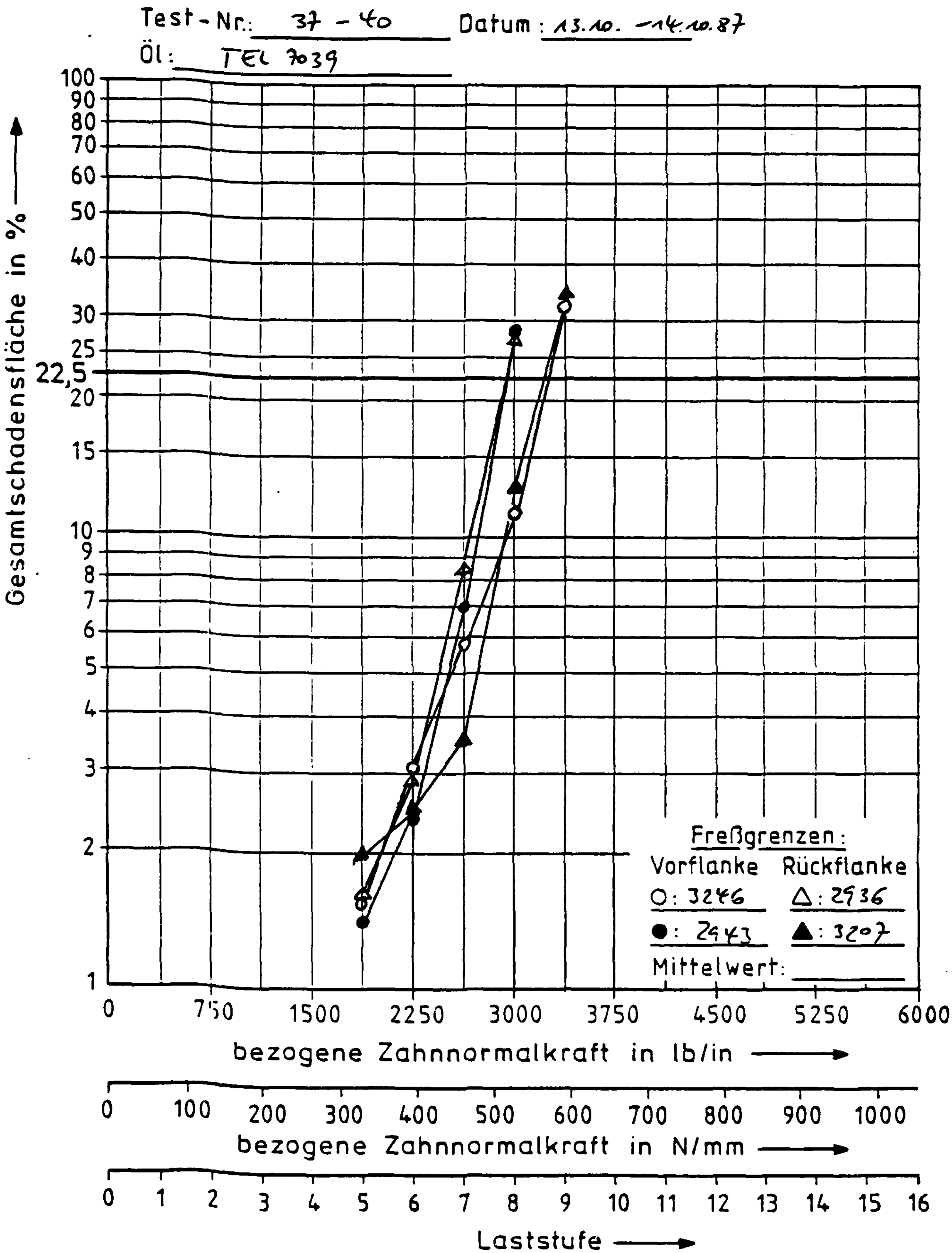
Versuchsprotokoll FZG - Ryder - Test

Test-Nr.: 33 - 36 Datum: 8.10. - 12.10.87

Öl: TEL 7039



Versuchsprotokoll FZG - Ryder - Test



FZG-Ryder Tests with TEL 7040   0-156 Mobil

Oil Supply System: Standard

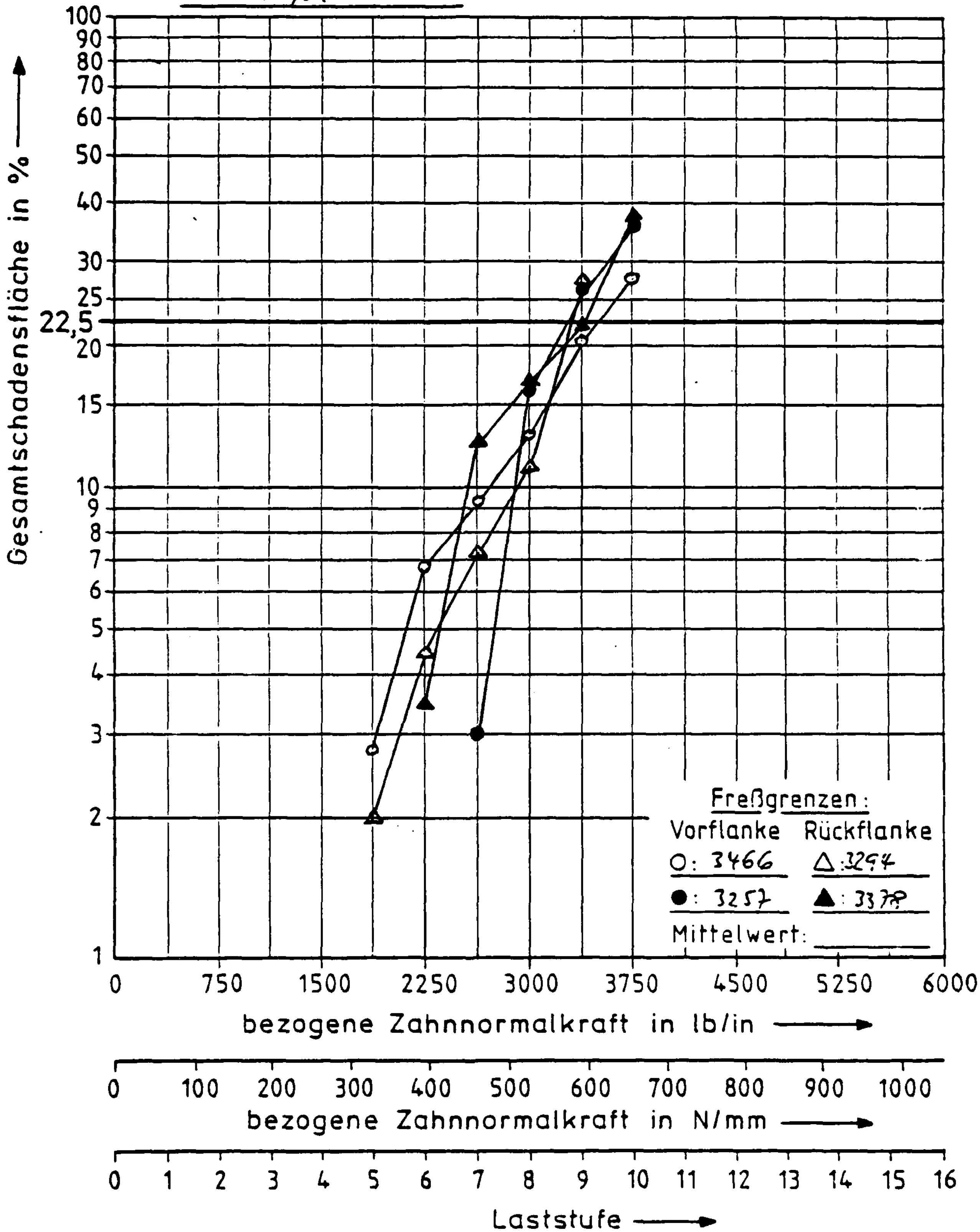
Lubricant Temperature: 74°C

Test No.	Date	Code Pinion	Code Gear	Flow Rate in l/min	Scoring Load F_{bt}/b in lb/in
25	1.10.87	24 977	25 037 ND	1	3466
26	1.10.87	24 977	25 037 NM	1	3294
27	2.10.87	24 994	25 054 ND	1	3257
28	5.10.87	24 994	25 054 NM	1	3378
29	5.10.87	24 997	25 057 ND	1	3368
30	6.10.87	24 997	25 057 NM	1	3307
31	6.10.87	24 999	25 059 ND	1	3039
32	7.10.87	24 999	25 059 NM	1	3412
				M =	3315 ppi
				S.D. =	130 ppi

Versuchsprotokoll FZG - Ryder - Test

Test-Nr.: 25- 28 Datum: 1.10. - 5.10.87

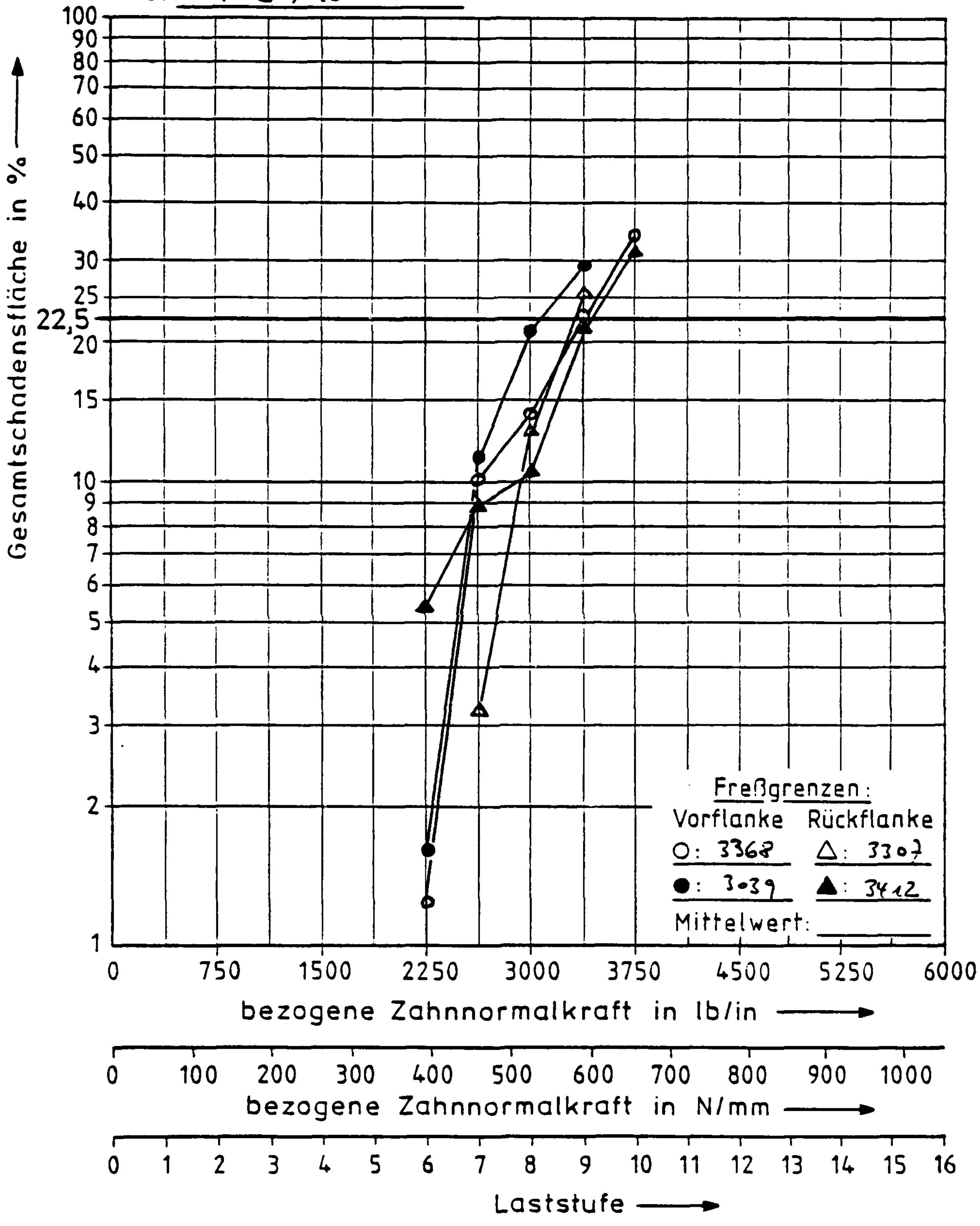
Öl: TEL 7040



Versuchsprotokoll FZG-Ryder-Test

Test-Nr.: 29 - 32 Datum: 5.10. - 7.10.87

Öl: TEL 7040



FZG-Ryder Tests with TEL 7041 Refoil C

Oil Supply System: Standard

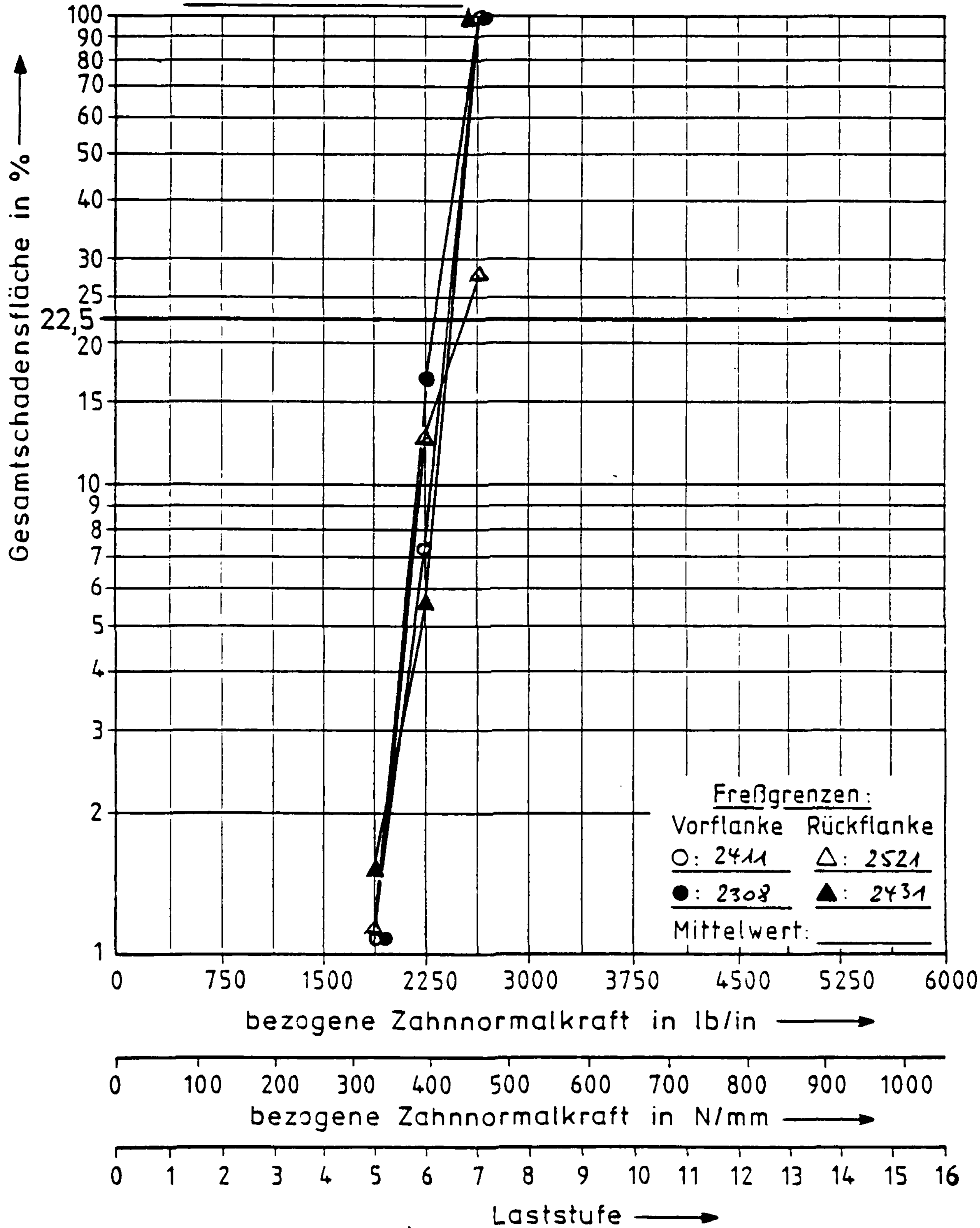
Lubricant Temperature: 74°C

Test No.	Date	Code Pinion	Code Gear	Flow Rate in l/min	Scoring Load F_{bt}/b in lb/in
41	16.10.87	24 976	25 036 ND	1	2411
42	19.10.87	24 976	25 036 NM	1	2521
43	19.10.87	24 967	25 027 ND	1	2308
44	20.10.87	24 967	25 027 NM	1	2431
45	20.10.87	24 987	25 047 ND	1	2211
46	21.10.87	24 987	25 047 NM	1	2465
47	21.10.87	24 984	25 044 ND	1	2063
48	22.10.87	24 984	25 044 NM	1	2218
				M =	2329 ppi
				S.D. =	156 ppi

Versuchsprotokoll FZG - Ryder - Test

Test - Nr.: 41 - 44 Datum: 16.10. - 20.10.87

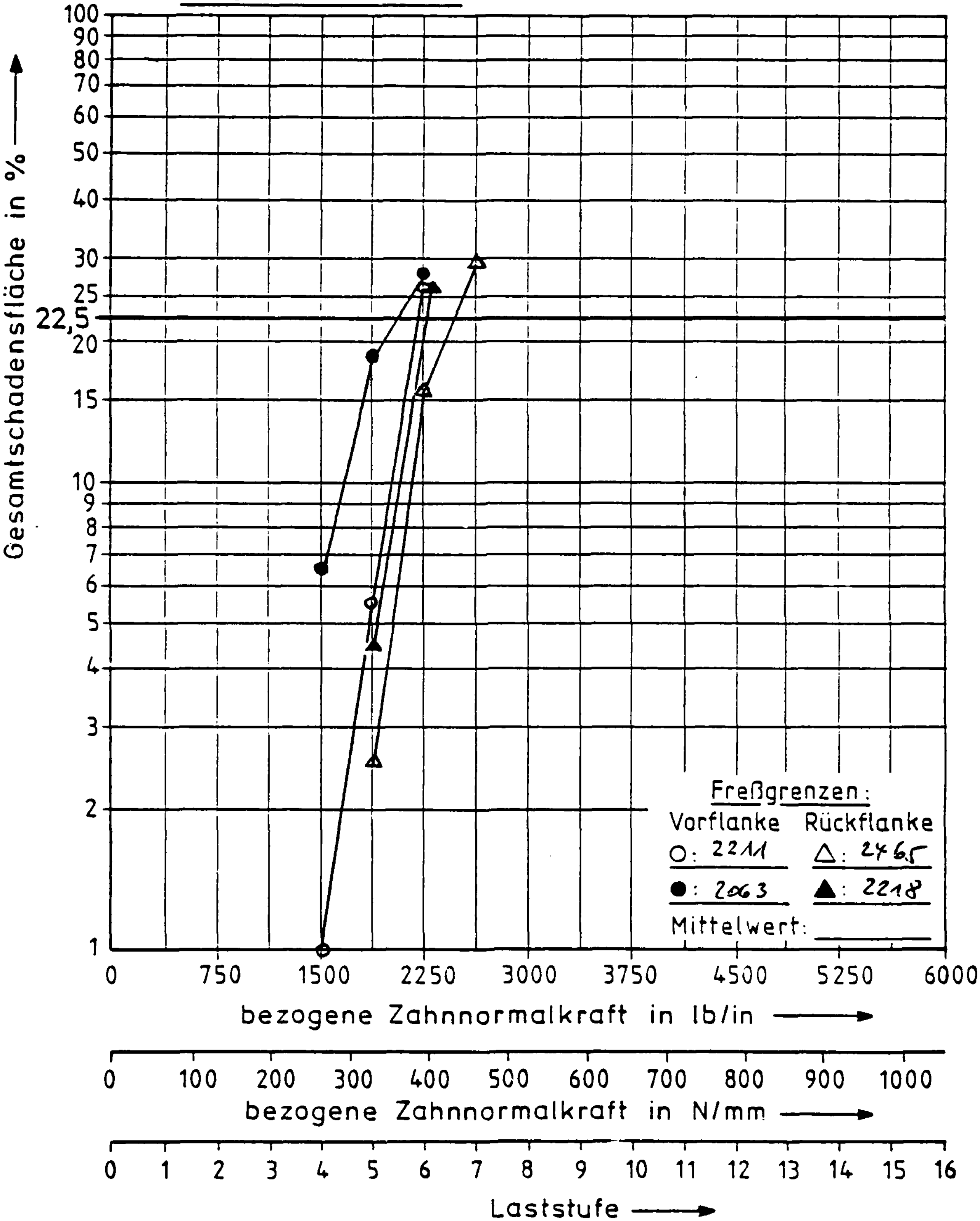
Öl: TEL 7041



Versuchsprotokoll FZG-Ryder-Test

Test-Nr.: 45- 48 Datum: 20.10.-22.10.87

Öl: TEL 7041



FZG-Ryder Tests with TEL 7041 Refoil C

Oil Supply System: High Temperature

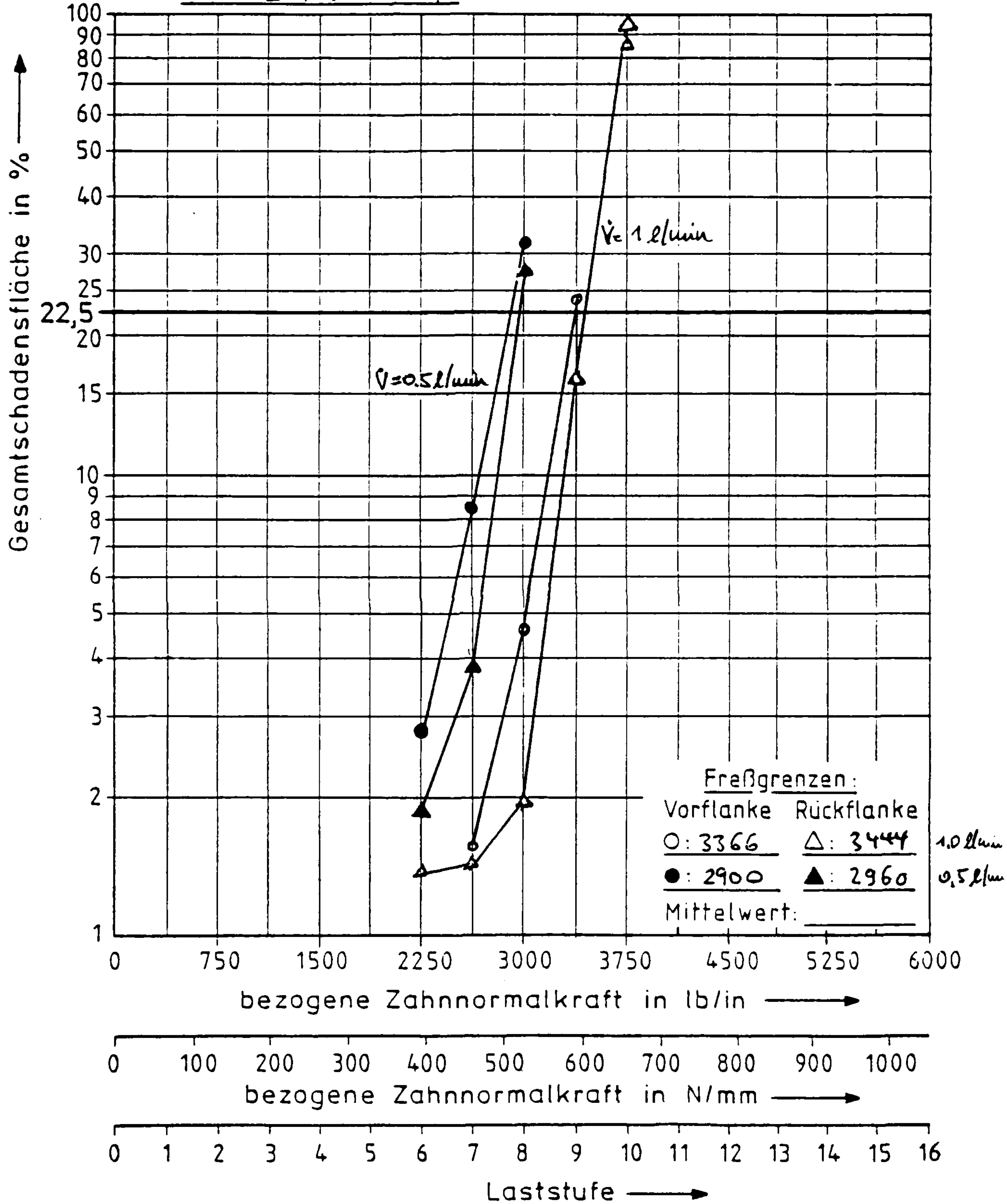
Lubricant Temperature: 74°C

Test No.	Date	Code Pinion	Code Gear	Flow Rate in l/min	Scoring Load F_{bt}/b in lb/in
49	1.8.88	25 001	25 061 ND	1	3366
50	2.8.88	25 001	25 061 NM	1	3444
	Tests No. 49 -50:			M =	3405 ppi
				S.D. =	55 ppi
51	2.8.88	24 970	25 030 ND	0,5	2900
52	3.8.88	24 970	25 030 NM	0,5	2960
	Tests No. 51 - 52:			M =	2930 ppi
				S.D. =	42 ppi

Versuchsprotokoll FZG - Ryder - Test

Test-Nr.: 49 - 52 Datum: 1.8. - 3.8.88

Öl: TEL 7041 Ref. Oil C



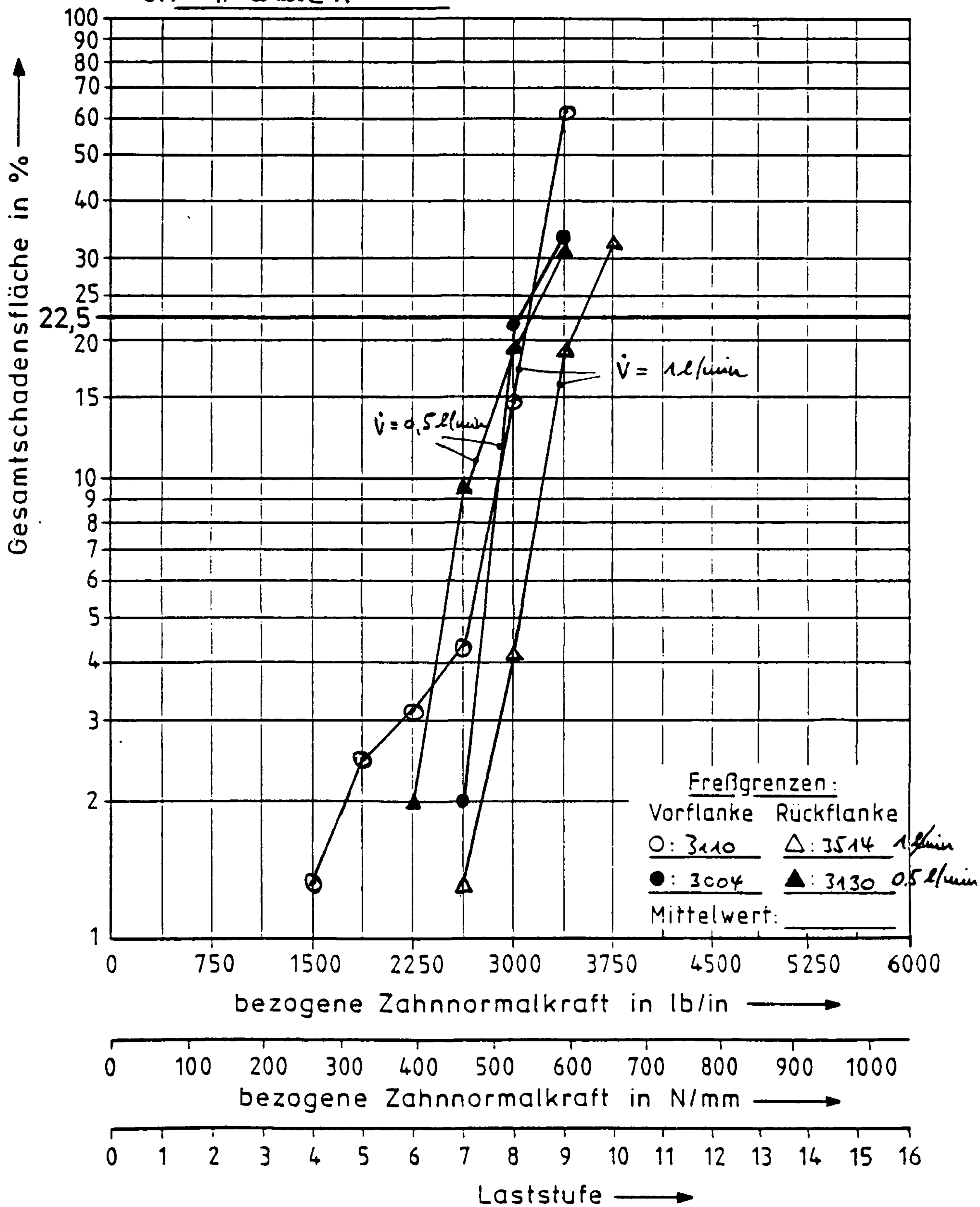
FZG-Ryder Tests with Hercolube A
Oil Supply System: High Temperature
Lubricant Temperature: 74°C

Test No.	Date	Code Pinion	Code Gear	Flow Rate in l/min	Scoring Load F_{bt}/b in lb/in
53	29.8.88	24 965	25 025 ND	1	3110
54	30.8.88	24 965	25 025 NM	1	3514
	Tests No. 53 - 54:			M =	3312 ppi
				S.D. =	286 ppi
55	30.8.88	24 990	25 050 ND	0,5	3004
56	31.8.88	24 990	25 050 NM	0,5	3130
	Tests No. 55 - 56:			M =	3067 ppi
				S.D. =	89 ppi

Versuchsprotokoll FZG - Ryder - Test

Test-Nr.: 53 - 56 Datum: 29.8. - 31.8.88

Öl: Hercolube A



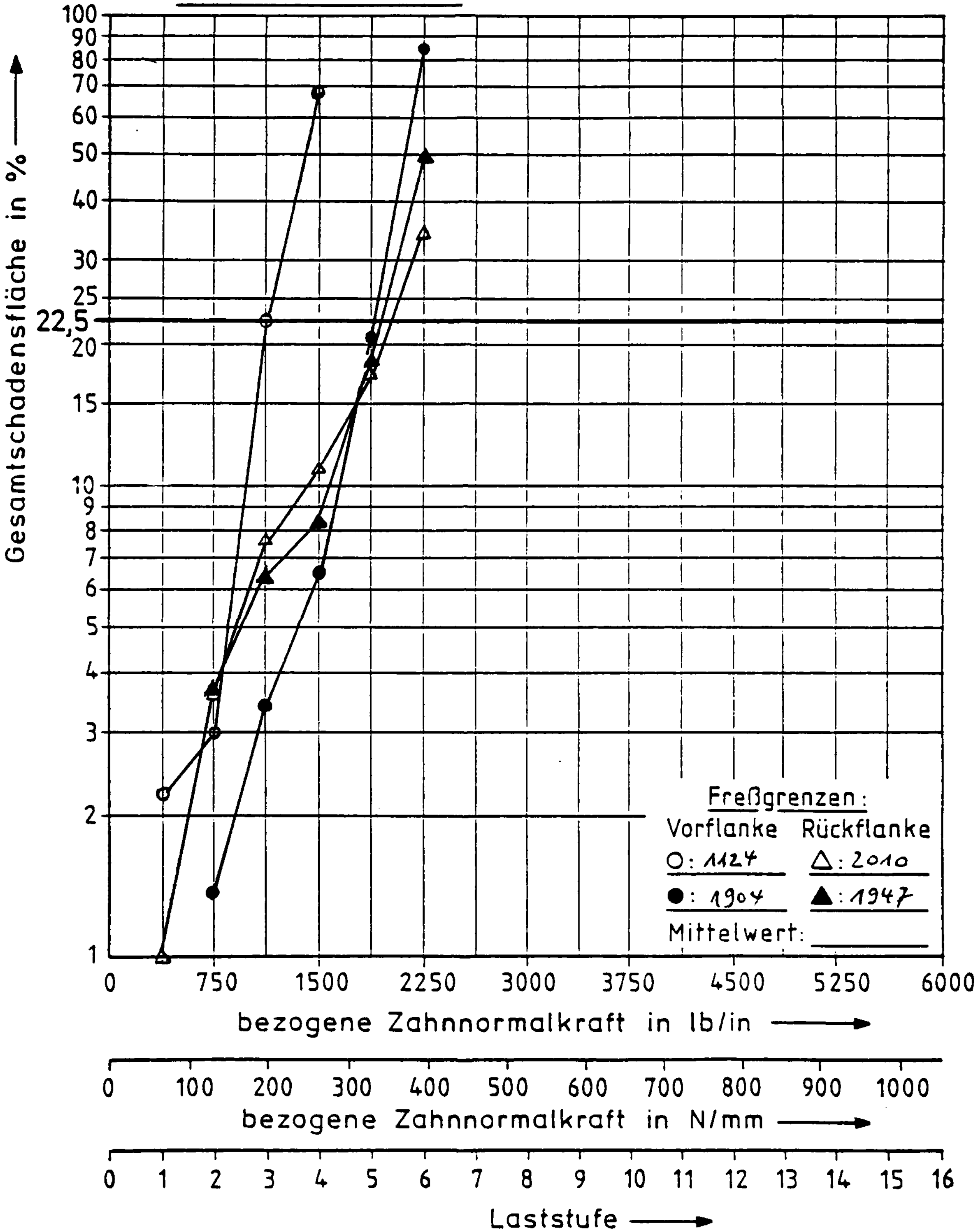
FZG-Ryder Tests with **Hercolube A**
Oil Supply System: High Temperature
Lubricant Temperature: 200°C

Test No.	Date	Code Pinion	Code Gear	Flow Rate in l/min	Scoring Load F_{bt}/b in lb/in	
57	2.9.88	24 966	25 026 ND	1	1124	
58	5.9.88	24 966	25 026 NM	1	2010	
59	6.9.88	24 981	25 041 ND	1	1904	
60	7.9.88	24 981	25 041 NM	1	1947	
61	7.9.88	24 969	25 029 ND	1	1493	Filter
62	14.9.88	24 969	25 029 NM	1	1744	
63	14.9.88	24 975	25 035 ND	1	1630	
64	15.9.88	24 975	25 035 NM	1	2285	
	Tests No. 57 - 64:			M =	1767 ppi	
				S.D. =	356 ppi	

Versuchsprotokoll FZG-Ryder-Test

Test-Nr.: 57 - 60 Datum: 2.9. - 7.9.88

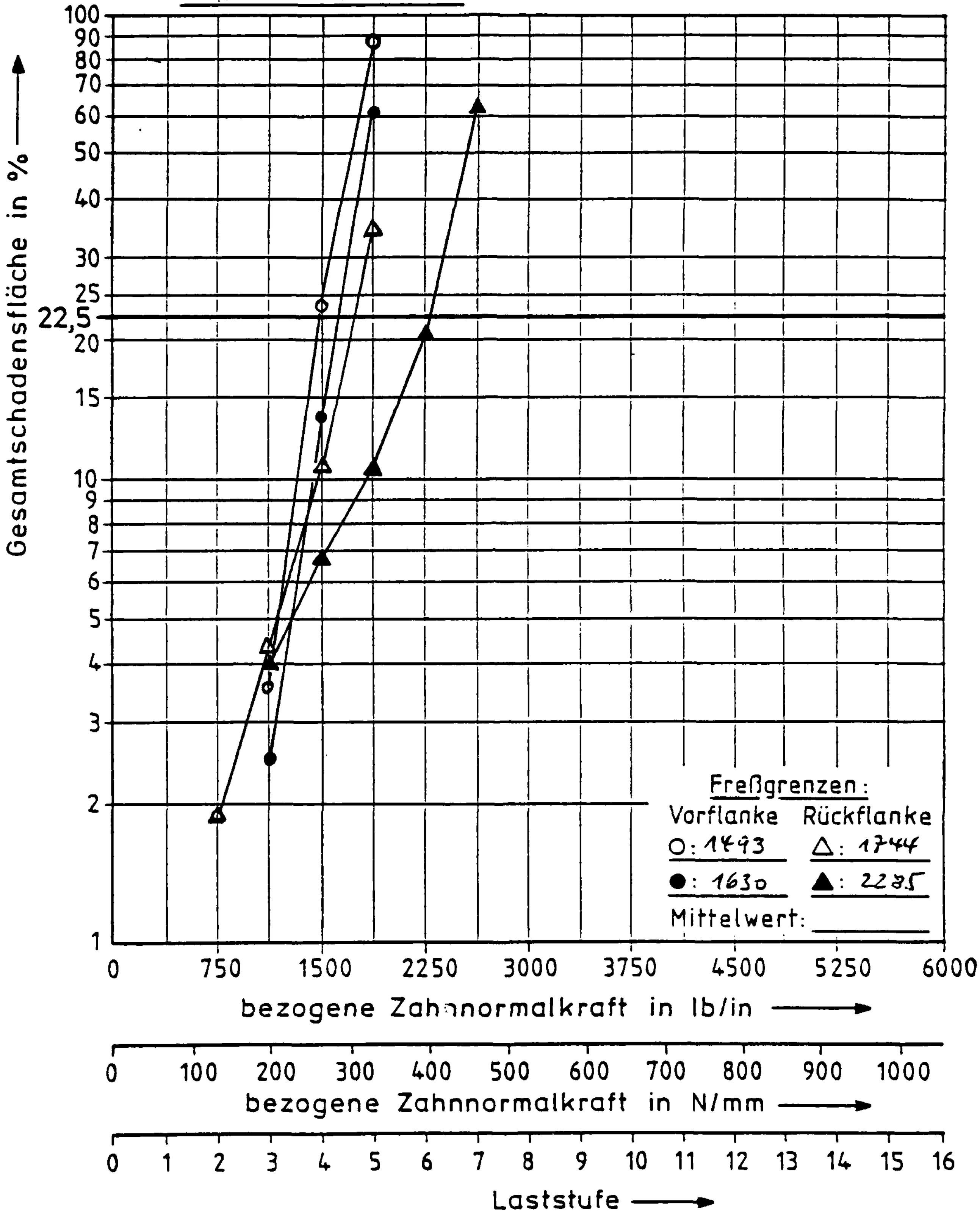
Öl: Hercolube A 200 °C



Versuchsprotokoll FZG - Ryder - Test

Test-Nr.: 61 – 64 Datum: 8.9. – 15.9.88

Öl: Hercolube A 200°C



FZG-Ryder Tests with TEL 7040 0-156 Mobil

Oil Supply System: High Temperature

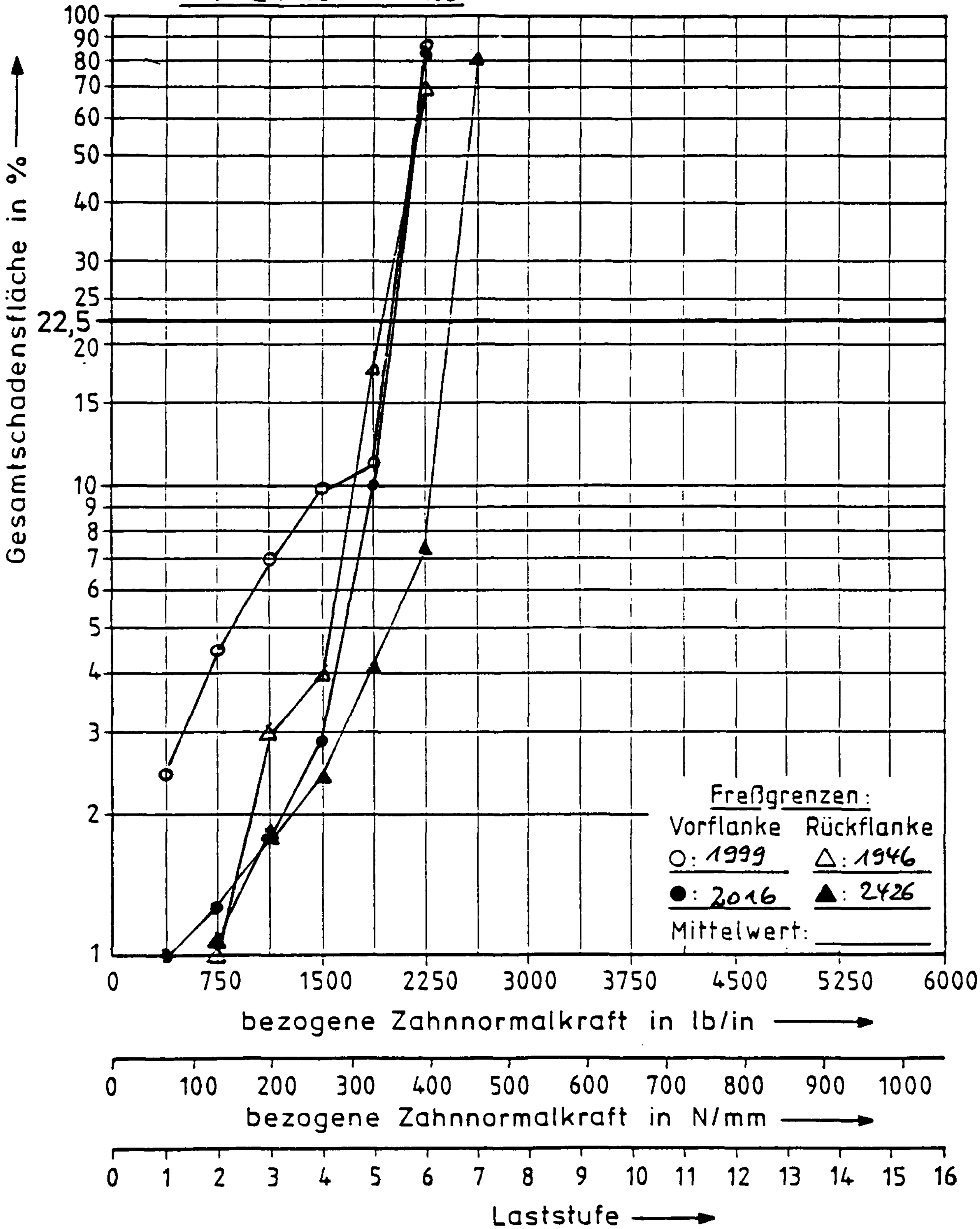
Lubricant Temperature: 200°C

Test No.	Date	Code Pinion	Code Gear	Flow Rate in l/min	Scoring Load F_{bt}/b in lb/in
65	20.9.88	24 979	25 039 ND	1	1999
66	21.9.88	24 979	25 039 NM	1	1946
67	22.9.88	24 982	25 042 ND	1	2016
68	23.9.88	24 982	25 042 NM	1	2426
69	6.10.88	24 983	25 043 ND	1	2420
70	7.10.88	24 983	25 043 NM	1	1752
71	10.10.88	24 988	25 048 ND	1	2491
72	11.10.88	24 988	25 048 NM	1	2413
	Tests No. 65 - 72:			M =	2183 ppi
				S.D. =	285 ppi

Versuchsprotokoll FZG-Ryder-Test

Test-Nr.: 65 - 68 Datum: 20.9. - 23.9.88

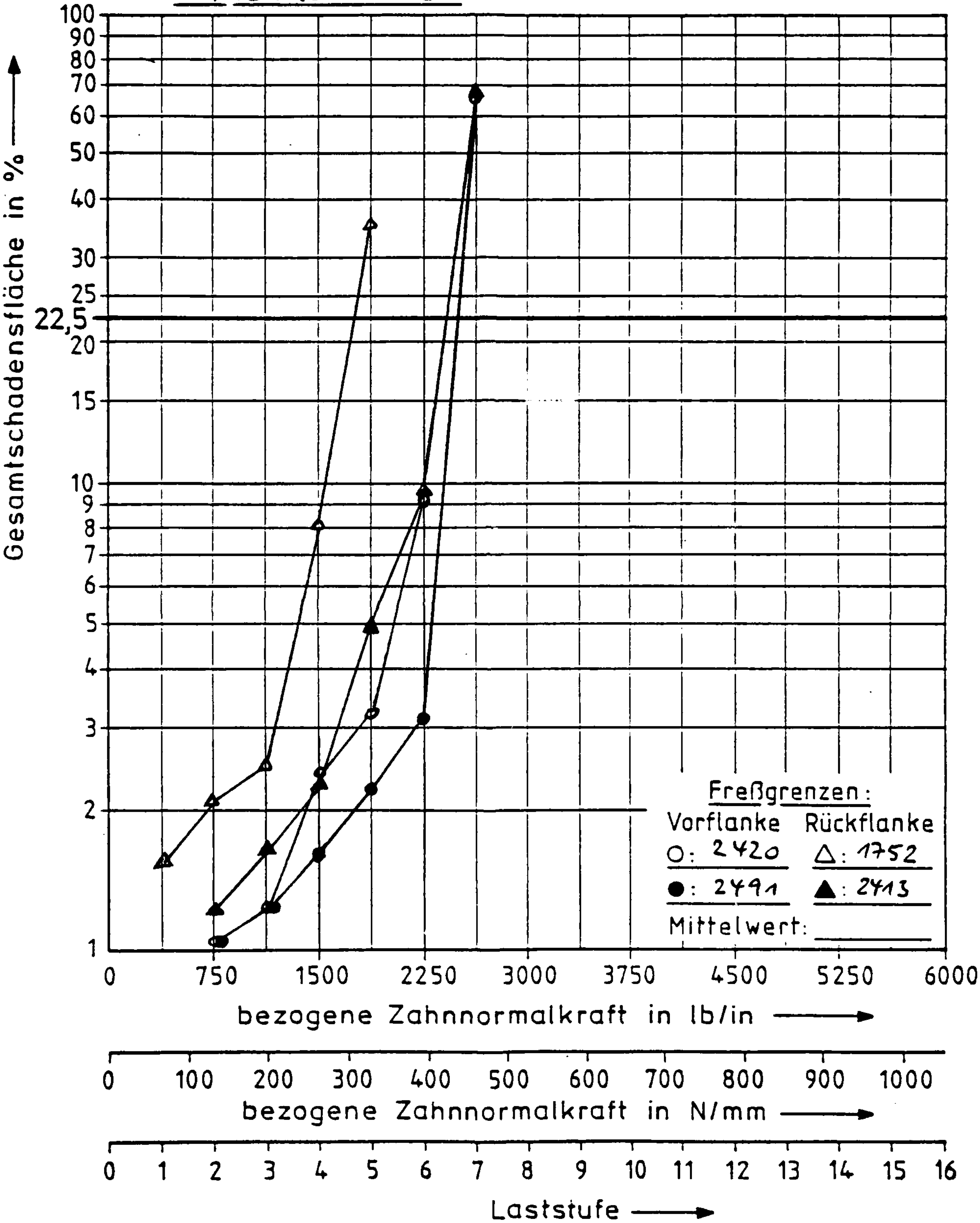
Öl: TEL 7040 0-16



Versuchsprotokoll FZG-Ryder-Test

Test-Nr.: 69 - 72 Datum: 6.10.-11.10.88

Öl: TEL 7040 0-156



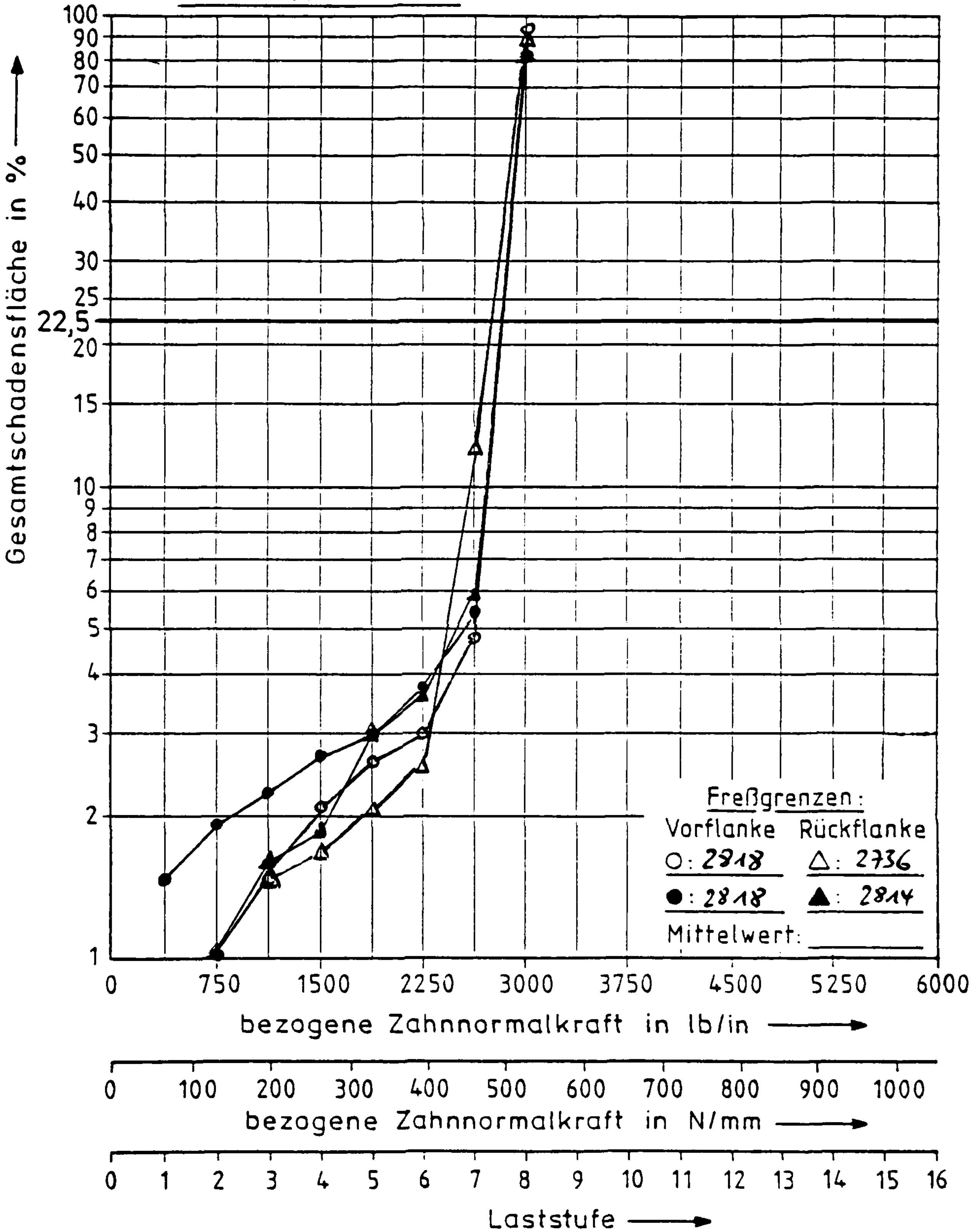
FZG-Ryder Tests with 0-160 Shell Asto 555
Oil Supply System: High Temperature
Lubricant Temperature: 200°C

Test No.	Date	Code Pinion	Code Gear	Flow Rate in l/min	Scoring Load F_{bt}/b in lb/in
73	13.10.88	24 989	25 049 ND	1	2818
74	14.10.88	24 989	25 049 NM	1	2736
75	17.10.88	24 992	25 052 ND	1	2818
76	18.10.88	24 992	25 052 NM	1	2814
77	19.10.88	25 002	25 062 ND	1	2434
78	20.10.88	25 002	25 062 NM	1	2089
	Tests No. 73 - 78:			M =	2618 ppi
				S.D. =	299 ppi

Versuchsprotokoll FZG - Ryder - Test

Test-Nr.: 73 - 76 Datum: 13.10.-18.10.88

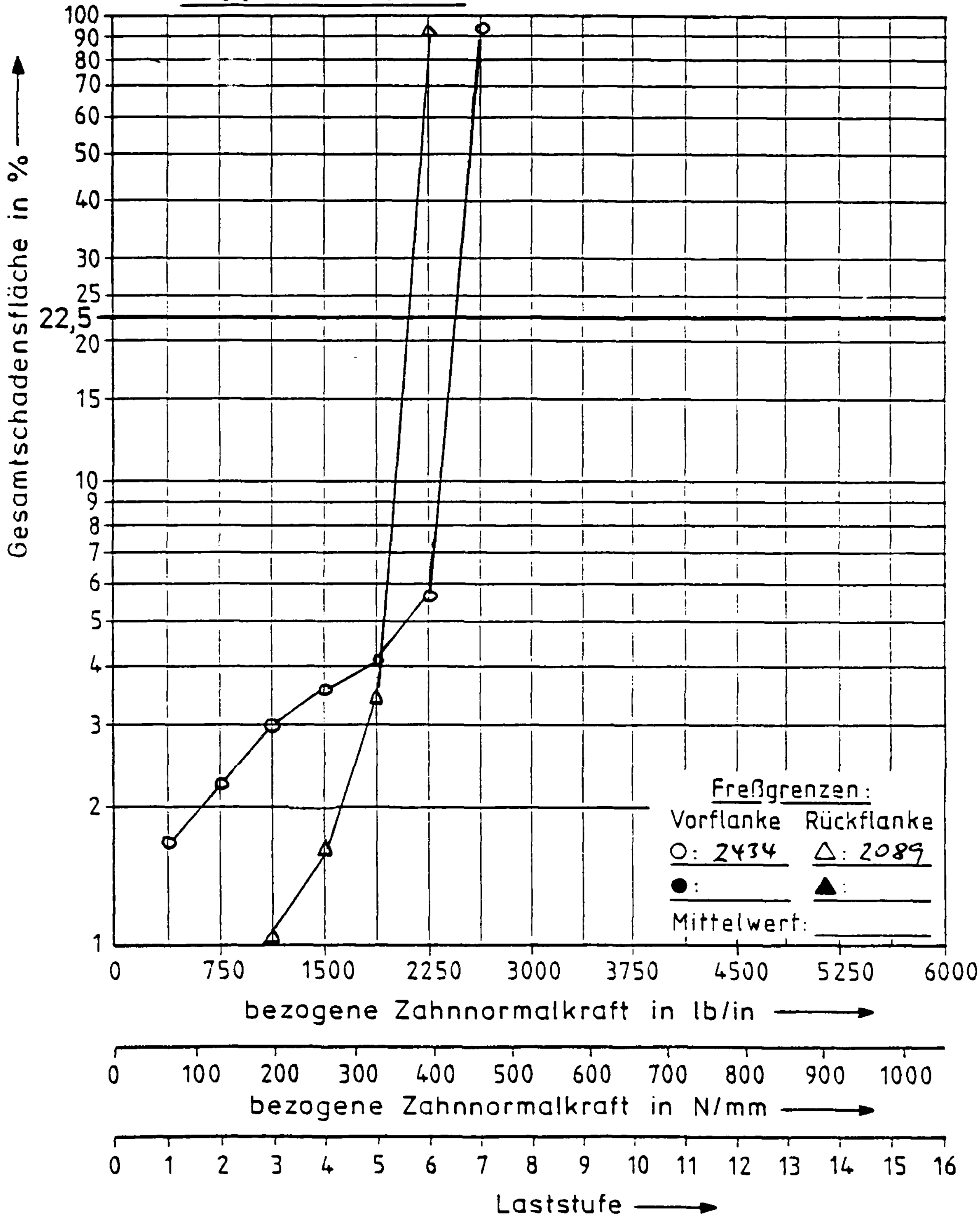
Öl: Shell Asto 555



Versuchsprotokoll FZG - Ryder - Test

Test-Nr.: 77 - 78 Datum: 19.10. - 20.10.88

Öl: Shell Asto 555



*U.S.Government Printing Office: 1989 648 056/04419